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THE MAIN DRAINAGE OF TOWNS.

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THE
MAIN DRAINAGE OF TOWNS.

BY

F. NOEL TAYLOR,

CIVIL ENGINEER, MEMBER OF THE INSTITUTE OF MUNICIPAL ENGINEERS,
AUTHOR OF "CIVIL ENGINEERING PRACTICE."

SECOND EDITION, REVISED.

With 6 Plates and 351 other Illustrations.

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PREFACE TO SECOND EDITION.

THE very favourable welcome accorded this volume on publication by surveying, municipal, medical, and other technical journals assured general acceptance, but the World War diverted attention to more urgent matters. Unfortunately, economic conditions following the War hindered construction work, and the utmost care over expenditure was necessitated owing to increased costs.

To bring this work up to date for this edition has involved the deletion of text referring to systems and appliances no longer in use, and of co-ordinating and rearranging certain sections. The subject of sewage disposal has been largely rewritten, as the activated sludge system seems likely to attain widespread adoption; also sewer construction required much revision, having regard to the economy effected by the extended use of concrete; whilst pumping practice has so changed that the chapter on Pumping of Sewage has needed bringing up to date. The author has been glad to avail himself of the opportunity of bringing the work in line with present-day conditions.

F. NOEL TAYLOR.

March 1927.

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THE MAIN DRAINAGE OF TOWNS.

CHAPTER I.

MAPS, PLANS, SECTIONS, AND PRELIMINARY ARRANGEMENTS.

Maps.—For an engineer to carry out a sewerage scheme to a successful issue, no matter how small, good maps and accurate plans and sections are essential; it will therefore be suitable for the first chapter of a book dealing with this subject to describe fully the use of such maps and sections. It is not proposed to show how such maps are prepared by the expert surveyor, as this is beyond the province of the work; nor will the art of levelling be discussed: the reader is assumed to be a surveyor and leveller beforehand.

To carry out sewerage schemes in the United Kingdom, engineers resort to the use of the Ordnance maps as a rule, except in complicated districts or in special cases where it is considered necessary to make a new map, owing to the accuracy of the existing ones being doubted. The value of the Ordnance maps only needs to be known to be appreciated, because the information they give is most detailed, and their accuracy nothing short of marvellous. They are made in sheets, usually 27×40 in., and to scales as set out in Table I.

Table I.—Scales of Ordnance Maps.

1. 1·013 in. to 16 statute miles $=\frac{1}{1,000,000}$.
2. 1 in. to 10 miles $=\frac{1}{633,600}$.
3. 1 in. ,, 2 ,, $=\frac{1}{126,720}$.
4. ¼ in. to 1 mile $=\frac{1}{253,440}$.
5. 1 in. ,, $=\frac{1}{63,360}$.
6. 6 in. ,, $=\frac{1}{10,560}$.
7. 25 in. ,, $=\frac{1}{2500}$.
8. 5 ft. ,, $=\frac{1}{1056}=$ 1 in. for 88 ft.
9. 10 ft. ,, $=\frac{1}{528}=$,, 44 ft.

Those which are most useful, for the preliminary work at least, are those drawn to the scale of 6 in. to 1 mile, and the Parish maps, drawn to the scale of 25·344 in. to 1 mile, and known commonly as the 6-in. and 25-in. maps.

After practice, one rapidly gets used to these maps and the information contained therein. In figs. 1 and 2 are given illustrations of these two maps

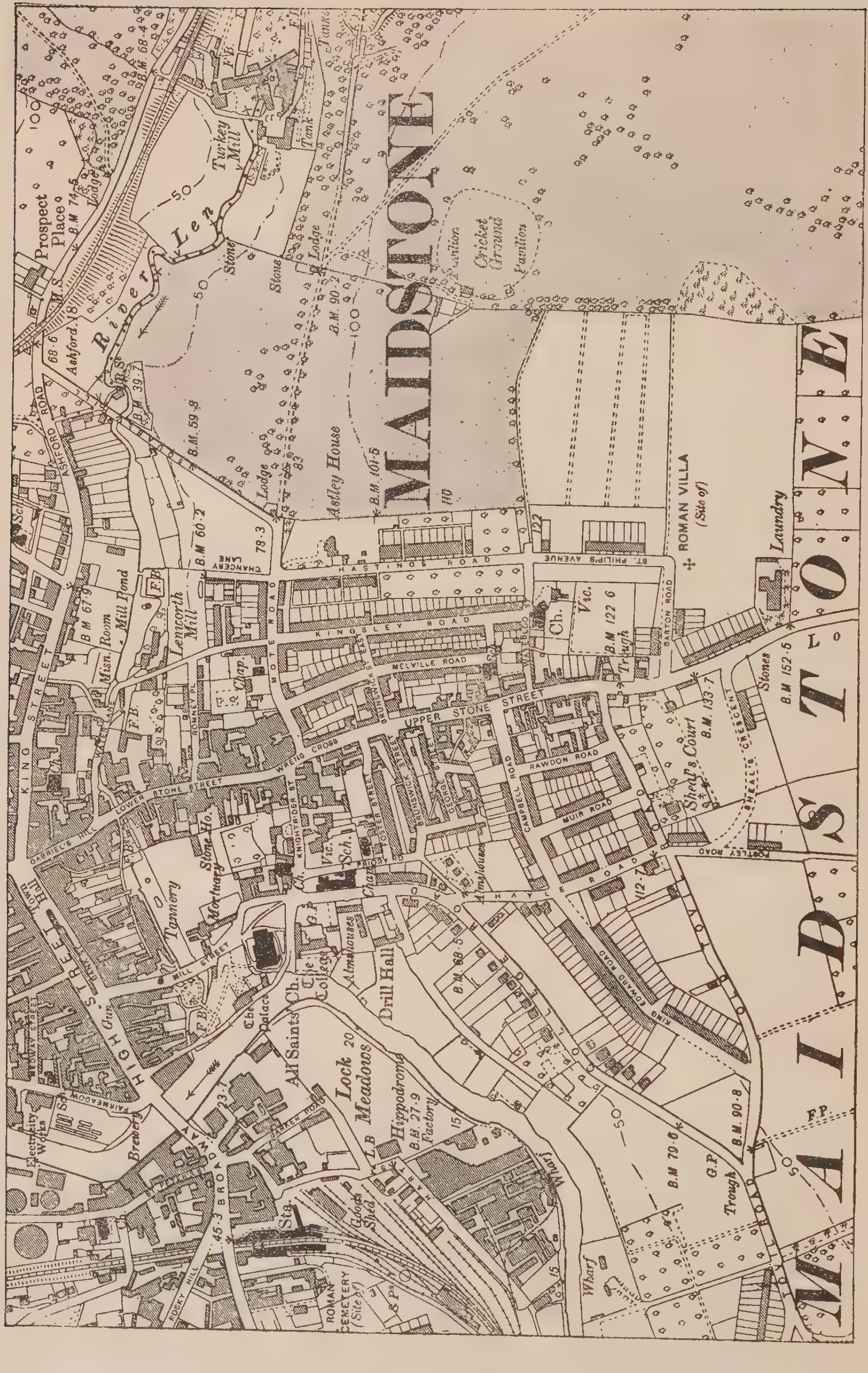


FIG. 1.—Example of Six-inch Map.

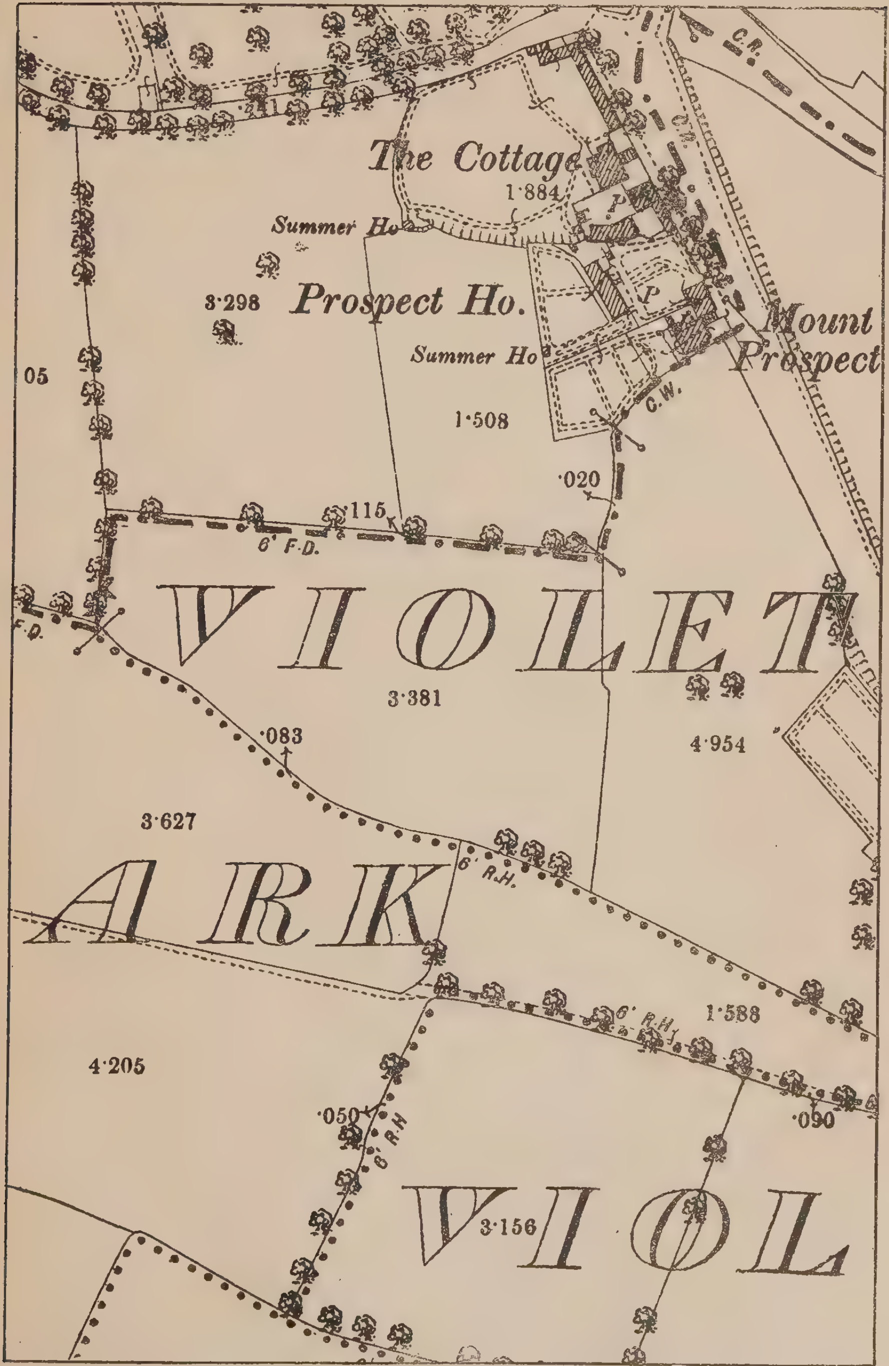


Fig. 2.—Example of Twenty-five-inch Map.

to actual scale, which will enable the reader to know them by their look in future.

The 6-in. map has special advantages for preliminary work because of the contour lines thereon, shown by being fine dotted, and the figures beside them. As no doubt the reader is aware, these lines pass through points of equal altitude above Ordnance datum, the numbers denoting these heights in feet above the mean tide level at Liverpool. Given, then, a set of maps of the district in question, by a careful examination the engineer can lay out his preliminary drainage areas, and see where it will be necessary to place the disposal works if pumping is likely to be necessary, or if there will be any great difficulties to be surmounted by reason of the general configuration of the ground. He will also, if necessary, be able to make trial sections of the ground, to give him a better idea of it. This will be done as shown in fig. 3; but the result will not have much value in flat districts owing to the distance apart the contours are, as compared with the scale of the map and the necessarily small vertical interval (viz. distance between the contours).

The 6-in. maps are of great value to the engineer, especially those engaged on roads and railways; but for sewerage works they are hardly large enough for many purposes, and, beyond a means of providing preliminary information in the earliest stages, are not of very much use, and the 25-in. map has a much wider application.

These maps have no contour lines, but some have spot levels, such as +25·72, which signify heights above Ordnance datum; these figures often prove useful in making trial sections. The value of the 25-in. maps lies in the area of each parcel of land being given in acres and decimals, which greatly facilitates the calculation of the drainage areas of the built-on and unbuilt-on land, and for urban districts are very useful. In towns, however, both the 6-in. and 25-in. maps are too small to be of much value, and the 5-ft. map (fig. 4), with spot levels thereon, is very useful, and provides a large amount of information to a very convenient scale.

Preliminary Plans.—Having decided what maps he will use, the engineer proceeds to go over the ground and check the accuracy of the map regarding its principal features. The maps are only revised at intervals, and in quickly growing towns (as towns contemplating drainage works usually are) a few new streets will have been made, which of course require measuring up and very accurately putting on the map. Copious notes should be made during this procedure of anything of a special nature.

Provided, then, that the engineer is fully satisfied of the accuracy of his maps, he can proceed to mark the drainage areas thereon, but with the use of contours and spot levels there is still a further and most important precautionary measure in the case of land in which there is any reason to anticipate sinkage. These remarks apply to those lands in coal- and salt-mining districts where constant subsidence is going on, in which case (unless the edition of the map relied on is very recent) care must be taken in checking the figures thereon. Again, a site chosen for a pumping-station or sewage disposal works, which would otherwise be eminently suitable, would, if liable to subsidence, have to be abandoned. Consultation of the mine plans is a useful precautionary measure to take.

On examination, the place selected will in most cases be found to have one or more *natural* watercourses running through it; and these being

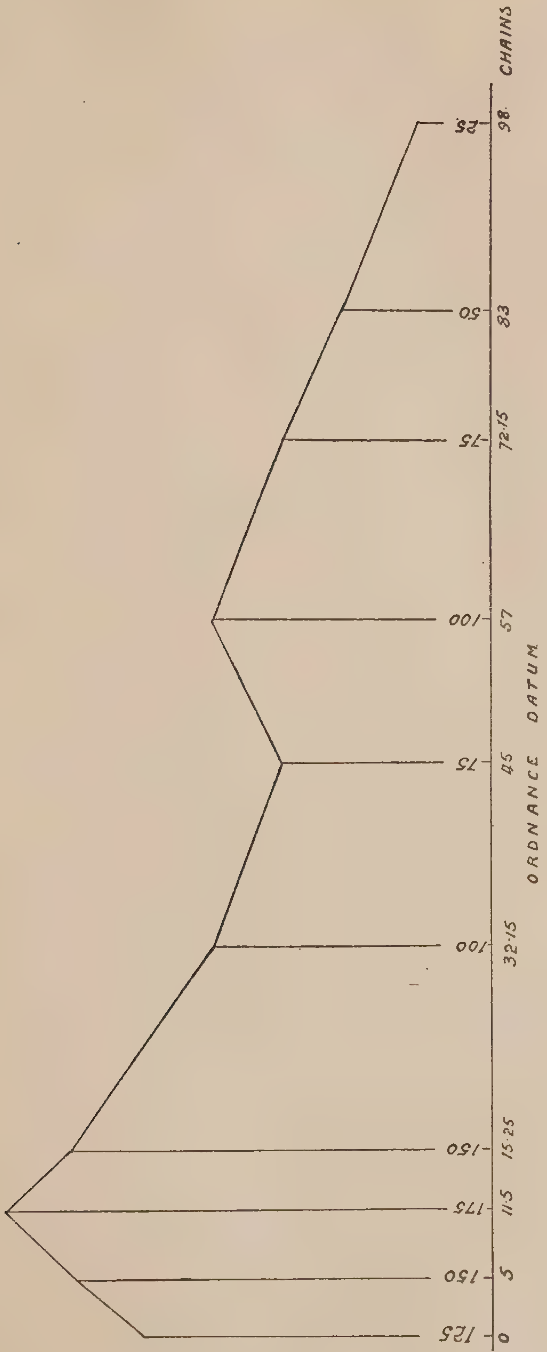

125
150
175
150
100
75
100
75
50
25
0
5
11.5
15.25
32.15
45
57
72.15
83
98
CHAINS
ORDNANCE DATUM

Fig. 3.

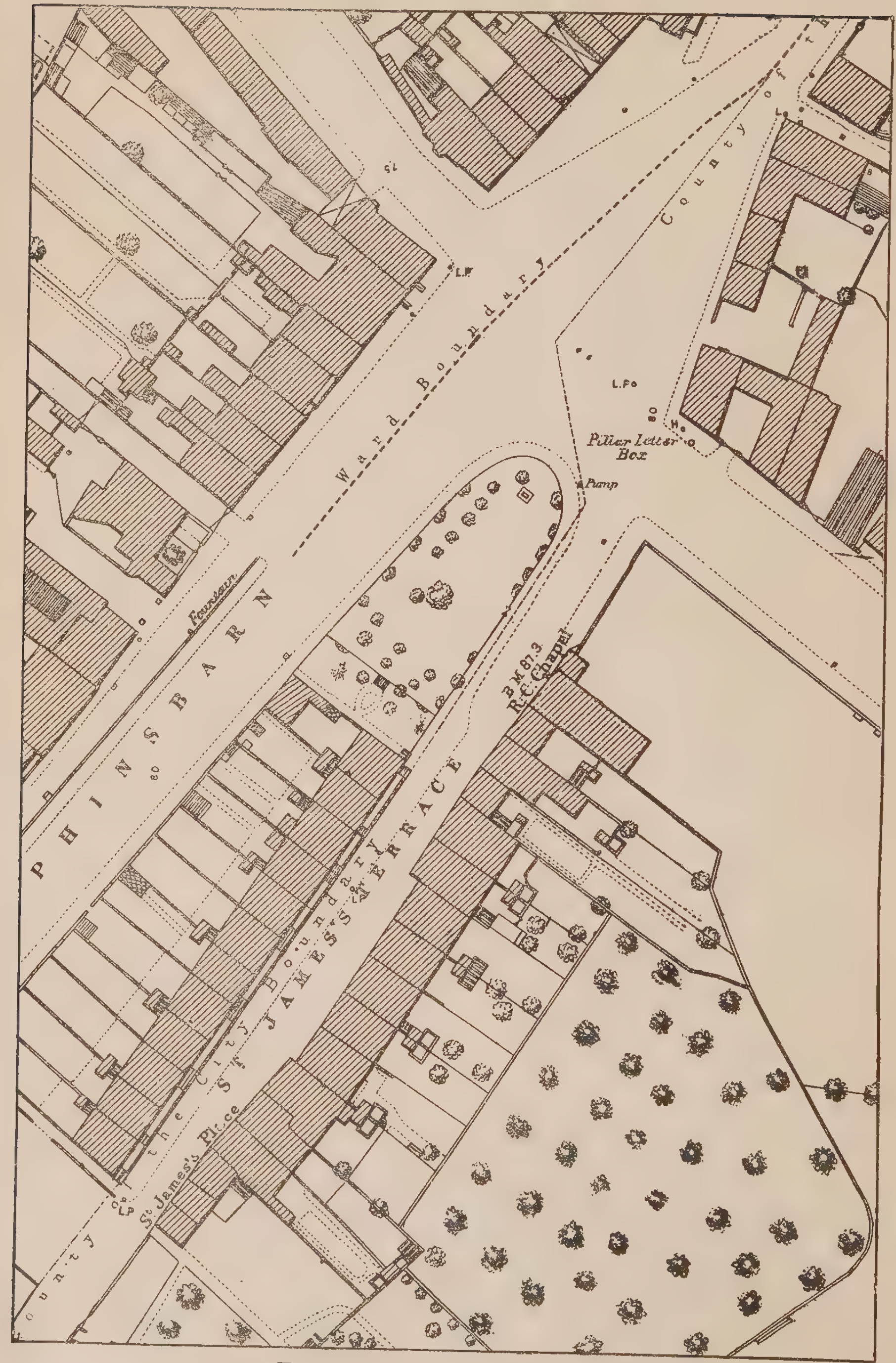


Fig. 4.—Example of Five-foot Map.

defined on the plan, will give the probable (but not necessarily essential) lines of the main sewers, because, unless the ground thereat is quite unsuitable for sewage disposal, the most natural place for the disposal works would be at a point along the river somewhere below the town, because this point usually serves the triple purpose of doing away with pumping, providing tolerably flat land to build the works on, and a suitable irrigation area when required, besides facilities for sludge disposal by boat if necessary. It must not be supposed, however, that this is to be a hard-and-fast rule. In many cases it may be cheaper to resort to pumping part of the sewage, or applying high-level sewage to raise low-level sewage to some intermediate point in a manner which will be set out further on. Great experience and discretion on the part of the engineer are required in this direction. Again, no modern sewerage scheme can be considered as effectual unless it provides for the drainage of the basements of all buildings : even then the level of the sewers must be such that there is no possible chance of flood or tidal waters causing sewage to back up the drains of these basements. If such should happen, the last state of that town may prove worse than the first. From this cause alone pumping may be rendered essential, especially in towns on the banks of tidal rivers. Dublin is an instance of a city where intolerable nuisance was caused in the low parts by flooding of basements from this cause, till the main drainage of 1908 effectually removed the evil by pumping the sewage to the disposal works, despite the fact that the city had been previously drained entirely by gravitation. The rivers will also at once determine the points for storm overflows. These points should be selected with care. Where a sewer crosses under either a river or stream, this point at once suggests itself by reason of the natural position, and also the reduction in the size of the sewer allowable, which will somewhat reduce the cost of this expensive part of the work. Intercepting sewers constructed to cut off a number of separate outlets into a river may conveniently use the original outlets as storm overflows. On the other hand, it must not be assumed that a special storm sewer is a waste of money. To discharge large quantities of storm water, which is often very foul, due to the streets being thoroughly scoured by a sudden storm, into a wide and sluggish part of a river is to give opportunity for causing subsequent nuisance; but, by a little forethought, the engineer will probably find, not far off, a part of the stream narrow and swift, which will be able to deal with these flood waters.

Provided with suitable maps one can lay down with tolerable accuracy the lines of the main sewers : in any case, those lines laid down will be the first trial sections which will be taken.

The next procedure is to define the drainage areas as follows :—

(*a*) The built-on area. This comprises the town proper wherever there are dwellings, business premises, paved and macadamised streets and areas, etc., from which all the surface water will find its way, in a short space of time too, into the main sewers.

It is upon this area that the existing population is considered in the calculations, but the future population has to be considered, and there is a second division, that is—

(*b*) The unbuilt-on area, which will, according to reasonable progress in building, be entirely built upon within thirty years. The reason that thirty years is the period adopted is because the Ministry of Health specify that term as suitable for repayment of the loan issued for carrying out the works.

Hence statistics have to be looked into showing the increase per cent. of the population for a number of years past, from which a reasonably accurate estimate for the future can be made. Even then, of course, local circumstances will affect the calculations. A town may have every reason for rapid growth due to some special newly formed industry, cases which have so frequently occurred in the past fifty years in the United Kingdom, and where the existing sewerage schemes are entirely inadequate; but such abnormal growth of towns is not at all likely to be anticipated in the future in the same degree as in the past.

Again, the growth may all tend towards a particular part of the town. In manufacturing towns this tends to increase along the low-lying lands near the rivers, while in purely residential districts the reverse is the case, this population seeking more and more the higher outlying districts, which are now brought by the tramway companies into such easy reach. New railways, with good land along the sides, are inducements to the growth of industries; but as so few are made in the United Kingdom nowadays, the question is hardly worth consideration at home, but abroad it is of the very utmost importance.

The direction of increase may also be ascertained from the comparison of two sets of Ordnance maps of different dates, say forty years; and, unless local circumstances point to any strong reason to the contrary, future extension may be assumed to follow the same lines. Having, then, as accurately as possible defined the position and extent of the area which will probably be built on (*b*), it must be marked on the map.

The third class of land to consider is that lying within the drainage area which is unsuitable for building. This land should be drained into the watercourses, special land drains (or sewers if required) being laid for the purpose, so as not to unduly tax the proposed scheme by large volumes of water for which there would be no monetary return, and at the same time materially reducing the first cost of the works. With these considerations in mind, it will only be a matter of careful forethought to mark on the areas *a*, *b*, and *c* for each branch and main sewer and storm overflows, from which a calculation of flow can be made, as will be shown later. It is hardly necessary to say that the preparation of these plans is a very important matter. The work demands great care; and, although presenting no difficulty to the old, experienced hand, yet to the younger engineer, who is perhaps carrying out a small scheme, which may in a few years develop into a large scheme, the work is often perplexing because of the two evils he has to contend with. Making the sewers too large, therefore liable to subsequent stoppage, and the production of bad smells at the ventilators, would soon create the idea amongst the public of the drainage being bad; making them too small would necessitate a thorough revisal of the scheme. While it is impracticable to make provision for the heaviest possible rainfall, risks of flooding, or unforeseen exceptional circumstances, any ill effects that may arise may be minimised by means of storm sewers of ample capacity. Some engineers assume that the rainfall over the whole area will find its way directly to the sewer. From a practical point of view this may save much time and trouble; but it is certainly more accurate to give special attention to the impervious portion of the area, viz. paved roads, house roofs, yards, etc.

For example, take the following instance given in *Drainage* by Messrs Dempsey & Clarke. A summer shower lasting twenty minutes supplied 2 in. of rain over an area of $\frac{1}{4}$ square mile, *i.e.* 1,125,000 cub. ft. of water to be discharged by the sewers. To prevent flooding, 56,250 cub. ft. of water would have to be removed per minute, or even if the sewer had a velocity of 1000 ft. per minute its sectional area would have to be $56\frac{1}{2}$ sq. ft.

It is with the object of dealing with cases of this kind that there are so many supporters of the "separate" system of sewerage, which, however, has never had any practical value, owing to the extra expense entailed. At the same time, old sewers put out of use by the new ones, provided they are not in the way of the latter, may be put to good use in removing surface water.

Before concluding these remarks on plans, it may be well to add a few words on the bad practice of placing too much information on the plan before testing its practicability. This will occur when using the 25-in. map in complicated districts: the engineer may lay out his sewers in accordance therewith on straight lines and place manholes at changes of direction, but afterwards finds, when taking levels and going over the ground, that the points so selected are useless, extra manholes having to be provided to ease the sewers round corners.

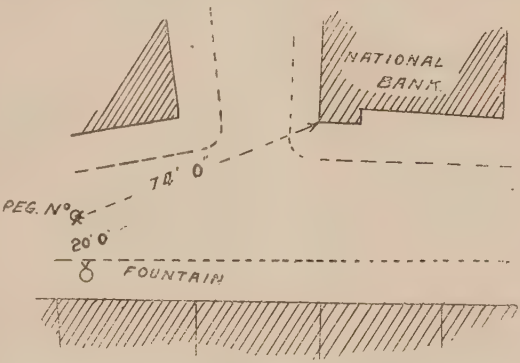


Fig. 5.—Fixing position of Pegs.

Sections.—The next important duty of the engineer is the preparation of the sections from the results of figures obtained by levelling. The sections play a more important part in a sewerage scheme than the plans, and are usually drawn (at least the working sections are) to a larger scale longitudinally than the plans, the vertical scale being larger still, in accordance with the usual practice. The work requires great care, especially in flat districts, where every inch of fall has to be made use of. When going over the ground and setting out on the plans the various salient points, pegs should be driven in the ground. These pegs should be good stout ones, properly formed, about 18 in. long and $1\frac{1}{2}$ in. to 2 in. square. For road surfaces and hard ground the use of iron or steel pegs is advisable, driven flush with the surface of the road, as pegs so driven must be capable of immediate future location, even after considerable intervals of time. Nothing is more troublesome than hunting for old pegs (often in vain), of whose position there are no records. At least two measurements should be taken to some important points, and entered in a book after the following style :—

Peg No. 57, centre of manhole 20, 74 ft. from S.W. corner of National Bank Building, and 20 ft. from public fountain on footpath, as in fig. 5.

For pegs in open ground, three large stones placed round them also serve as an additional precaution.

When taking the sections, every opportunity should be taken of referring to the Ordnance bench marks in the district as a check on their accuracy, which need hardly be doubted (except in the cases pointed out), and also as a very valuable check on the results obtained by the leveller himself. In all cases the sections should be referred to the Ordnance datum, and in seaboard and low-lying districts the Ordnance datum should be used on the sections. This, of course, becomes impracticable when the heights are great, and the datum line should then be referred to in the following way: "Datum 100 ft. above Ordnance datum," and so on as the case may be. Bearing these precautions in mind, each main, each branch sewer, and each storm overflow may be levelled and sections plotted. The distances between the points where the staff is held must be measured on the ground, and noted in the field book in the proper column. They should run consecutively from end to end of the sewer in question, and may be expressed in chains, yards, or feet. In any case, the use of the chain is to be advised in preference to tape measurements, but the 66-foot chain has no advantage in sewerage work where areas are not calculated from the chain measurements; in fact it is likely to be confusing; therefore the 100-foot chain is strongly recommended. All possible information should be entered in the level book as the work proceeds.

Plate I. is a typical example of a town sewer running, as far as practicable, along the centre of the roadway, as shown on the plan. The total length is 1875 ft. The case is fairly straightforward. The ground in the first portion is fairly flat, while in the second part it is much steeper and falls rapidly towards the river. When the surface of the ground is plotted, the laying down of the sewer in the most economical method is a matter which demands much consideration and forethought. More often than not there will be other considerations than the surface profile for determining its correct position.

The level of the outfall sewer is the principal one. But in the case of a sewer built to take branches from other districts already in existence, and perhaps having separate outfalls, the invert level of these sewers may provide a determining factor in the case.

Again, the aim of good sanitation is to have all sewers with a self-cleaning velocity, and when only running one-sixth full. This is a stringent regulation, and may seem very well in theory, but in large towns it is very rare to see it carried out in practice; if this velocity is maintained when the sewer is half full, a good deal has been done towards the ideal. It is no doubt a sound practice to carry out the principle of "getting all the fall you can" within reasonable limits, but for large city sewers the engineer will more often than not have to be satisfied with about 10 ft. per mile, or even less; and in order to provide for as much velocity as possible with dry-weather flow, he must turn his attention to the actual construction by the methods pointed out in a later chapter. Pipe sewers, however, cannot be laid at this rate of fall, although the Ministry of Health have sanctioned schemes, to the writer's knowledge, in which 12-in., 9-in., and 6-in. pipes were laid with falls as little as 1–400, 1–300, and 1–200 respectively, giving a velocity of about 2·25 ft. per second when half full, which is the maximum carrying capacity of pipe sewers, and a condition rarely occurring. In cases of this sort the subsequent efficiency depends to a very great extent on the individual attention of the engineer to the accurate construction of the sewer, and the quality of the pipes used, joints, junctions, etc.

Depth.—The depth below the surface is the next important factor. Great depths mean heavy expenditure, not only of capital available but also of subsequent revenue, in repairs and house connections. The former can be avoided in the proper construction of the work in the first instance, and the latter in carrying up the house connections to within a few feet of surface level when the sewer is built; or, if the sewer is a large main outfall, it may be a saving of expense to lay a smaller sewer at a higher level for house connections and surface water, and to connect the same to the main by a stand-pipe in a manhole, as in Plate III. On the other hand, shallow sewers (below 4 ft.) will, under public roadways at least, always be subject to fracture, and such shallow depths must be avoided. In cases where a short length of the roadway has an abnormal dip, and the maintaining of this depth would entail heavy depths in other parts, the making up of the roadway might be resorted to and found economical; in a big city, however, this would probably be impracticable. As before stated, the deepest cellars should be capable of gravitational drainage, and there should be no liability of flood water backing up the sewers; such conditions make the most favourable depth for the sewer to be greater than 5 ft., but isolated buildings could be dealt with by pipes running for some distance parallel with the main before joining it if the procedure proved cheaper. Such cases should be examined during the levelling if possible, but generally would not be anticipated till the section was plotted. In drawing out the sections the usual practice is to draw the datum and surface lines in black, the vertical depth lines in blue, with red at a change of gradient in the sewer; while the drain would be drawn in red if new, and black if old work. Some engineers lay in the invert line only on the section; others draw the sewer to its correct depth on the vertical scale; but for pipe sewers it is good practice to lay on the surface of the finished concrete bed, because when this is laid to a true gradient the pipes will naturally be in the correct gradient. The depth of cutting is usually coloured red, while any bank, which may occur only in exceptional cases, is yellow. The figures for the heights above datum are in black. It is also very useful to calculate the height above Ordnance datum of the proposed invert of the drain or top of the concrete bed, as the case may be, at points near an Ordnance bench mark whose accuracy is beyond doubt, and figure it on the section in red figures thus (51·72), placing a circle round it, as shown in Plate I.

Setting Out.—This will greatly facilitate the setting of the pegs in the trench by the clerk of works, by relieving him of the necessary calculations, which, although simple, are, like other mathematical work, best done in the office. For instance, say a peg marking the position of a manhole has its surface found by levelling to be 71·12 ft. above Ordnance datum, and by measurement the invert of the manhole is found to be 7 ft. 6 in. below the surface of the road or ground at that point, obviously, then, the height above Ordnance datum of the invert is 71·12—7·5=63·62. The accuracy of such a calculation naturally depends on the correctness, and to a great extent the scale (which must be large), of the sections. This setting out of a trench for a sewer accurately by the use of the level is work in which beginners often get confused. For instance, referring to Plate IA, an opening is being made at A and another at B. It is required to find the proper depth for a peg at the invert level at the point B. It is found by actual measurement that the invert level of the *old* sewer at A is exactly 8 ft. below the surface of the road. Its height over Ordnance datum is therefore 53·90—8=45·90. Near to it is an Ordnance bench mark whose height is 54·40.

The sewer is laid to a gradient of 1–187·5, and the distance from A to B is 800 ft. Now 800÷187·5=4·21 ft., which must be subtracted from 45·90=40·69. This, then, is the height of the invert above Ordnance datum at the point B; and as the surface level is found to be 52·99, the depth of cutting is 52·99—40·69=12·30. The peg would be set approximately 12 ft. 4 in. below the surface at the point in question, and then a series of levels would be run to finally set it at a point 54·40—40·69=13·71 below the bench mark. It is the operation of carrying out this process of reverse levelling which perplexes the inexperienced engineer. There is no real difficulty, however. To give an example of how it is done in practice:

The level is set up at X and the staff on the Ordnance bench mark, the reading being 5·81. At the invert level of the old sewer it is 14·31. At Z the reading is 0·92. The level is then shifted midway between Y and Z, reading at Y 1·21, at Z 4·20.

The level, next set midway between Z and B, Z reads 4·10 and B 9·59.

Shifting the level to nearer B for convenience, 3·12 is read. Obviously, then, in order to set out a peg at 40·69, it is necessary to read on the staff 52·99—40·69=12·30+3·12=15·42, when the peg will be found at correct level.

Examples of Sections and Plans.—Plate I. illustrates a typical piece of main drainage in a large town.

An old sewer used to continue east towards the river from manhole 9, but, being too small for its purpose, it was decided to rebuild it, leaving the old sewer to deal solely with the district west of manhole 9. The size of the sewer is 5 ft. 6 in. × 3 ft. 6 in., egg-shape. The two parallel lines show the invert and the top water-level of the sewer running half full. The depth of the sewer is fixed by the depth of the invert of the old sewer at manhole 9. The ground is favourable for a uniform gradient as far as 1125 ft., in which there is a drop of 6 ft., giving a gradient of 1 in 187·5. Here the ground starts falling rapidly towards the river, and for 377 ft. the fall is 1 in 29. It would, of course, have been quite practicable to lay the sewer from point 1125 in an even gradient of 1 in 20·8 to the main intercepting sewer, but the fall would have been too rapid and the depths uneconomical; hence it was decided to break the fall at manhole No. 2, which is also a storm overflow, and give it a drop of 9½ ft. From manhole No. 2 to the main sewer the gradient remains the same, while the storm overflow, which, by the way, is 3 ft. circular, has a fall of 1 in 121, which is necessitated by the highest level of spring tides in the river, so as to prevent backing up of the water therein. In any case, with the necessary large volumes of water coming down it, the fall is sufficient for the purpose.

Plate II. shows an example of a main outfall sewer running as directly as convenient across comparatively open country, and presenting some out-of-the-way features. Manhole No. 1 on plan is the junction of three important sewers from an urban district. The best available site for the pumping-station, which raises the sewage 10 ft. 9 in., for the purpose of a gravitational run to the outfall works lower down, is that shown. The problem was to lay a main outfall sewer 5 ft. by 3 ft. 9 in. to it from the point in question.

For 610 ft. the fall is 1 in 47, when a rapid rise in the ground is encountered, whereon are constructed a canal and single line of railway. Obviously to disturb such works would be impossible; no suitable land whatsoever for purification could be found on the north-west side of these obstacles, and any attempt to construct artificial filters would have led to abnormal pumping: these, with other considerations, caused tunnelling under the railway and canal to be the least expensive procedure. Hence there is a portion of the sewer from 610 to 1010=400 ft. at a gradient of 1 in 110, of which 102 ft. is cut and cover, and the remainder in tunnel. From 1010 to 1651=641 ft. the gradient is increased to 1 in 38, but beyond this a flatter fall is necessary in order to maintain a uniform fall of 1 in 158 to the pumping-station. Nothing unusual occurs till point 2990, at which there is a small stream. It would have been quite possible to syphon under the stream, but the ground was bad, and it was decided to carry the sewer over it as two cast-iron pipes 36 in. in diameter, after providing for a storm sewer at the north bank of the stream.

Details of such construction will be given later.

Plate III. presents a somewhat novel case, in which sundry other improvements besides drainage were carried out at the same time.

Manhole No. 1 is placed at the confluence of two important sewers, for which it was decided to build a new 3-ft. circular outfall as shown.

A uniform gradient of 1 in 105 was decided upon. The depth gave much difficulty in varying from very deep, 34 ft., to very shallow, 4 ft. deep, part of it being driven in a tunnel. It will be noticed that a part of the ground lies very low. In this quarter the houses and population were as low as the land itself, but on certain leases expiring the local authority took over the property on either side. Hence it was an easy matter to improve the roadway by raising it in parts as much as 8 ft. In order to run the sewer as intended, this was essential because of the conduit 8 ft. deep running as shown. It was quite impossible to disturb this by reason of its being an old water right; and hence the construction shown was decided upon as the most economical, the sewer, when passing over the conduit, being built upon a foundation of rolled steel joists, supported on piers at either side, to avoid any pressure on the arch of the culvert, which was left intact.

This sewer introduces another important construction—that of a subsidiary sewer, laid parallel to the main sewer at the part where it is very deep and in tunnel. The houses on the west side of manhole 2 have basements which require draining. Those on the east side have no basements.

To connect the former with the main would have involved needless expense, and a 6-in. sewer was laid for 681 ft. from manhole 10 to manhole 12, having a fall of 1 in 78 and a vertical drop at manhole 8 of 18 ft. This mode of construction may be advantageously employed in similar cases. It is quite possible to lay one sewer vertically over the other: if, however, the low-level one is cut and cover, it is not advisable, unless done some considerable time after the filling in has had time to become thoroughly consolidated. In fact it will often be more prudent to lay two sewers, one on each side of the road, especially if it is a wide one.

Tabulating Information.—It would be quite impossible to give examples of all the different obstacles that are met with, and to describe the methods of overcoming them; those chosen provide for most contingencies. It remains to add that all levelling operations should be most carefully checked before any definite schemes are drawn up. When drawing up preliminary plans for a proposed sewerage scheme, it is usual for the engineer to furnish a report on the district for the benefit of the local authority or other parties concerned; and the method of drawing up such a report, and the information necessary to include in it, would be briefly as follows, the order of the various items being left to the discretion of the engineer:—

1. A general description of the district, stating whether it is low-lying or high ground, and the general altitude above sea-level.

2. The constitution; that is, any information as to the local authority, when the sanitary authority was formed, who controls the roads, and since when.

3. The geological formation, stating what it is formed of, whether there are any dips or faults, and if so, in what direction. Any information as to coal measures to be carefully noted, and if working the same has caused appreciable sinkage from time to time. Any salt mines or metalliferous mines should be mentioned.

4. The rainfall of the district should be very carefully ascertained in the manner shown in Chapter III., any previous records being carefully consulted.

5. The maps of the district accompanying the report should be fully described, special districts being marked on in distinctive colours, and referred to here.

6. The acreage of the several districts should be noted.

7. The roads should receive mention. All private roads should be coloured on the maps and referred to here.

8. The prospective building ground must also be marked on the maps and referred to, its acreage being ascertained and noted, mention being made of the proportion of the whole area that this land is supposed to be.

9. The valuation of the district.

10. The urban and poor rates.

11. The population, making note of any large institutions which form a large part of this, such as asylums, workhouses, colleges, etc.

12. The prospective population, calculated in a manner already described.

13. The number of houses in the district.

14. The death-rates from all causes, and from zymotic diseases especially.

15. The natural drainage of the district, stating where the storm waters at present pass off in general.

16. The water supply, where it comes from, and if all houses are supplied, mentioning cottages which have public fountains, etc. The consumption per head per day in summer and winter, and the quantity used by the large institutions referred to. State if w.c.'s are in general use or not.

17. Mark on the maps, as far as it is possible to ascertain, all the existing sewers, distinguishing between public and private ones. Fully describe the direction, size, fall, condition, capacity of discharge, ventilation, and outfall

of the principal existing sewers, stating also what drains into them, and describe them as "Sewer No. 1," "Sewer No. 2," etc., and if they are under the charge of the sanitary authority or not. Ascertain when they were built, if possible, and the engineer who constructed them.

18. Describe fully any purification works in the district, stating the principle on which such purification is based, the general condition and efficiency of the works, and the method of disposing of sludge and effluent.

19. Any pumping plants or ejectors to be carefully inspected and referred to, noting their maximum capacity and efficiency when inspected.

20. Describe any system of cesspool at present in existence, giving a general description of the prevalent methods of construction, ventilation, mode of emptying, and disposal of solids; carefully ascertain the overflows, and note. Compare the present state of affairs in this direction with the by-laws of the district.

21. Ascertain the sub-surface water-level at a number of different points from a bench mark at the surface, and refer it to the Ordnance datum. Examine all private wells in the district, and note their general condition. Ascertain if they are liable to contamination by existing system of drains, and if the sanitary authority have power to close up all private wells.

22. Mention if the system will be entirely gravitational, or if pumping all or part of the sewage will have to be resorted to; and if so, why.

23. Describe the position and plan of the proposed disposal works, and give particulars as to the methods of precipitation, sludge disposal, and effluent outfall.

24. Tabulate all places which have not at present sufficient means of drainage.

25. Describe the proposed new sewers.

26. In the case of small seaboard towns, the fullest information regarding the tides must be obtained, including the direction and duration of all eddies.

CHAPTER II.

PRINCIPLES OF HYDRAULICS AND HYDROSTATICS.

The subject of hydraulics is one which is debated upon at considerable length by engineering writers. Drainage may rightly be considered as a branch of hydraulic engineering in that it concerns the flow of liquid to a large extent; but that part of the wide and complex subject of hydraulics which immediately concerns the reader is that dealing with the flow of water in pipes, sewers, culverts, and open channels, and in the stability of walls to resist the static pressure of water.

A study of hydraulics is really rather part of an engineer's technical education than a matter having direct bearing upon the laying out of sewerage. Work and calculation are now so much facilitated by the use of published tables that it is not necessary to go very deeply into the subject here.

The main points which concern the reader may be defined as—

1. The flow of water in pipes.
2. The flow of water in open channels.
3. Sewer flow.
4. Measurement of flow.
5. Stability of walls.

Elementary Principles.—For the practical purposes of the hydraulic engineer the surface of still water is considered to be horizontal, because the force acting upon it is almost entirely that of gravity. The condition of equilibrium of water in a single vessel is that its surface must be everywhere at right angles to the resultant of the forces which act upon it. The other forces, such as capillarity, surface tension, etc., are for practical purposes negligible, as also is the slight curvature of the earth's surface. Not only, however, is this surface acted upon by gravity, but also by the natural pressure of the atmosphere, the average of which is taken at 14·6 lb. per square inch, near the sea surface level. It is upon this that depends the phenomenon known as suction, in which a column of water can be sustained to a height of about 34 ft., due to atmospheric pressure alone, and upon this principle the syphon acts; the explanation is as follows:—

When vessels containing liquid communicate with each other, there will be equilibrium when the surfaces of the liquid in the vessels are on the same horizontal plane, provided always, of course, that these surfaces are all subjected to the same atmospheric pressure. But if the pressure per square inch on the surfaces of the liquid is not the same in each case, then one of two things must result, viz.:

1. Motion, or
2. The difference of level of the two surfaces of liquid must be proportional to the pressures thereon.

In the syphon, for instance, there are two legs, one longer than the other, the short leg being submerged in the liquid and the air exhausted from the tube ; there is a difference of pressure, due to two unequal columns of water, with the result that motion takes place.

Then there is the force of gravity, which causes motion along an open channel. The term open does not necessarily imply that the channel in question is open to the atmosphere, but that the free surface of the water is subject to atmospheric pressure, as would be the case in any sewer not running full ; and sewers, excepting in special cases which will be pointed out later, do not run more than half full. This is in contradistinction to pipes under pressure greater than that of the atmosphere, which will also be considered further on.

The actual weight of a cubic foot of water is, at 60° F., 62·33 lb. avoirdupois, to be correct. But in most hydraulic calculations engineers adopt the figure 62·5 as being most suitable for general calculations. In an open channel, gravity is then the only force acting on the liquid therein to cause motion, and this force applies to liquids in the same way as it applies to any other falling body assumed to be falling *in vacuo*, and the value of this force is 32·1908 ft. acceleration per second per second. That is to say, in every second the rate of fall is increased 32·1908 ft. per second, or to formulate the above reasoning,

$$V=2\times\sqrt{32{\cdot}1908h},$$

which is, for ordinary engineering calculations, transformed into the simple equation,

$$V=8\sqrt{h}.$$

That is to say, V, the velocity in feet per second, is equal to 8 times the square root of the distance from the original surface of rest vertically. This is the fundamental equation for flow, but, as will be pointed out further, it is modified in practice.

In a vertical pipe obviously the entire force of gravity acts on the liquid therein, while in an open channel truly horizontal there will be no motion beyond that due to gravity caused by the actual depth of liquid therein, which is inconsiderable.

It is the intermediate position between the two which is of principal concern ; that is, where the channel is gently inclined to the horizontal surfaces. Let G be the force of gravity=32·2.

Let H be the difference in level between the two ends of the channel or pipe, and

Let L be the length of that channel, L and H being in the same units.

Let V be as above.

Then
$$V=G\times\frac{H}{L};$$

or if L=2 miles and H=20 ft.,

$$V\ (\text{theoretically})=32{\cdot}2\times\frac{20}{5280}\times 2$$

$=0{\cdot}244$ ft. per second velocity in the channel. If there were no retarding forces, the water would flow on and on in the channel with an ever-increasing velocity. It is these forces, however, which enter into the question, the main retarding force being friction.

Hydraulic Mean Depth.—What is known as *hydraulic mean depth* is a quantity equal to the sectional area of any stream flowing in a conduit (which may be a circular pipe, full or not, a sewer, canal, or in fact any channel) divided by the length of the wetted portion of that conduit, or the *wetted perimeter*.

It will be quite obvious that the hydraulic mean depth (which will be referred to as H.M.D.) is, in a circular pipe, equal to half the radius when full or half full, because it is either the area divided by the circumference or half the area divided by half the circumference; but when at any other degree of fulness, over or less than half, the calculation is more complex.

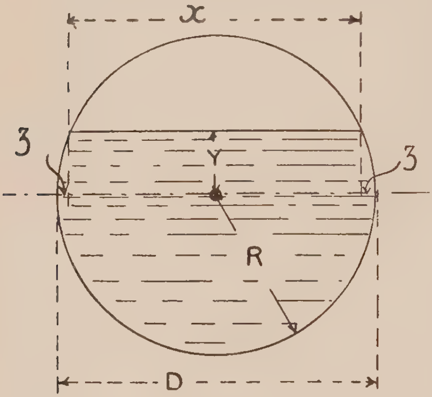


Fig. 6.

Referring to fig. 6, it is necessary to find x, the width of the water surface, and

$$x=\sqrt{R^2-y^2}\times 2,$$

R being the radius and y as shown.

The small quantity

$$z=\frac{2R-x}{2}.$$

Now the chord of half the arcs between top water-level and the centre is

$$c=\sqrt{y^2+z^2}.$$

The length of the two arcs above the centre

$$=L=\frac{8c-2y}{3}.$$

This is then added to the lower half of the pipe to find the wetted perimeter.

For any rectangular section the calculation of H.M.D. is quite a simple matter, but in sewerage schemes such forms are never used for sewers. On the disposal works, however, the channels usually are of this shape: in such cases the best proportion of width to depth is 2 to 1, because this gives the greatest possible H.M.D. with the least expenditure of material, and hence the greatest carrying capacity, seeing that such is proportional to $\sqrt{\text{H.M.D.}}$

For instance, let d be the depth of any rectangular conduit, then under the above conditions

$$\text{H.M.D.}=\frac{2d^2}{x\times 2d}=\frac{2d^2}{4d}=0{\cdot}5d.$$

Hence the H.M.D. of such a section is equal to half the depth as it is in a circular culvert, viz. half the radius.

c having been determined experimentally, the following equation is obtained by transposition :—

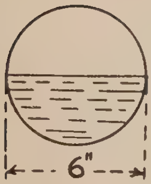
$$V^2=\frac{G}{c}\times\frac{H}{L}\times\frac{S}{C},$$

$$V=\sqrt{\frac{G}{c}\times\frac{H}{L}\times\frac{S}{C}}.$$

Hence

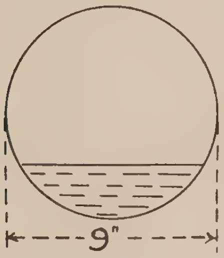
$$V=100\sqrt{\frac{H}{L}\times\frac{S}{C}}.$$

That is to say, V will give the velocity in any channel in feet per second if H, L, and $\frac{S}{C}$ are known. This bears out the previous statement of the velocity being proportional to the H.M.D., and also to the square root of the inclination. Now, as the velocity is dependent on the $\sqrt{\text{H.M.D.}}$, obviously, if a channel has the greatest possible area of water with the



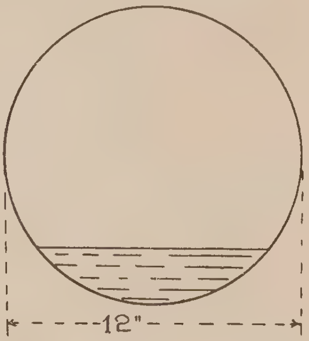
H.M.D =1·5

FIG. 7.



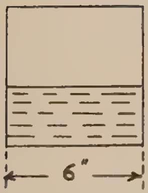
H.M.D = 1·434

FIG. 8.



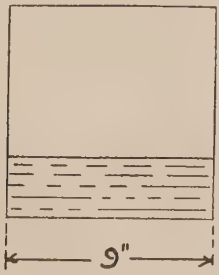
H.M.D = 1·347

FIG. 9.



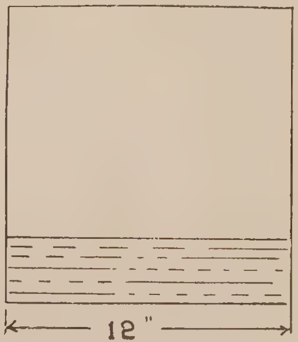
H.M.D =1·333

FIG. 10.



H.M.D. = 1·229.

FIG. 11.



H.M.D = 1.065

FIG. 12.

smallest possible border, it will have the greatest possible velocity, and hence the greatest discharging capacity.

Assume an 8-in. square rectangular section running half full. H.M.D.$=\frac{64}{32}=2$, as already pointed out. If, however, the channel is three parts full, this relation no longer holds good, and $\frac{48}{20}=2{\cdot}4$; and, again, if it only runs one-quarter full, H.M.D.$=\frac{16}{12}=1{\cdot}33$, which conclusively proves that such a form of channel is quite unsuitable for maintaining a regular velocity under varying conditions.

That the H.M.D. has an important influence upon the carrying capacity of any conduit is seen by the comparative diagrams in figs. 7–12.

Formulæ for Flow.—Of the numerous formulæ evolved by hydraulicians for estimating the flow in open channels, conduits, and sewers, Kutter's is generally regarded as one of the most suitable on account of its wide field of application and accuracy. It gives the value of the coefficient C in the expression

$$v=\mathrm{C}\sqrt{mi},$$

m being the H.M.D. and i the inclination. The latter is equal to $\frac{h}{l}$ where h is the fall in a definite number of feet l.

That is to say, if the fall is 4¼ in. or 500 ft.,

$$i=\frac{0{\cdot}35416}{500}=0{\cdot}000708.$$

According to Kutter's formula,

$$\mathrm{C}=\frac{23+\frac{1}{n}+\frac{0{\cdot}00155}{i}}{0{\cdot}552+23+\left(\frac{0{\cdot}00155}{i}\right)\frac{n}{\sqrt{m}}},$$

n, the coefficient of roughness, is tabulated in Table IA.

The following example shows the application of the Kutter formula:—

Find the value of C for a rectangular conduit made of well-pointed brickwork, the width of the conduit being 6 ft. 3½ in., the depth of water 11 in., and the fall 4 ft. 11 in. in 1000 ft.

The width of the channel is 6 ft. 3½ in.$=6{\cdot}29$ ft.; the depth of water is 11 in.$=0{\cdot}92$ ft.; the wetted perimeter $p=6{\cdot}29+0{\cdot}92+0{\cdot}92=8{\cdot}13$ ft.; the area $\mathrm{A}=6{\cdot}29\times0{\cdot}92=5{\cdot}7868$ sq. ft.; the hydraulic mean depth $m=5{\cdot}7868\div8{\cdot}13=0{\cdot}7118$ ft. The inclination $i=59\div(12\times1000)=0{\cdot}00492$. From Table IA, the value of n for well-laid brickwork is 0·013, and that of $1\div n=77$. Substituting these values,

$$\mathrm{C}=\frac{23+77+\frac{0{\cdot}00155}{0{\cdot}00492}}{0{\cdot}552+\left(23+\frac{0{\cdot}00155}{0{\cdot}00492}\right)\times\frac{0{\cdot}013}{\sqrt{0{\cdot}7118}}}=110.$$

TABLE IA.

Character of Channel or Conduit.	n.	$\frac{1}{n}$.
Clean well-planed timber: very smooth neat cement: clean and smooth glazed iron and glazed stoneware pipes	0·010	100
Masonry smoothed with cement (one-third sand): very clean smooth cast-iron pipe	0·011	91
Unplaned timber: ordinary cast-iron pipe: selected sewer pipes, well laid and thoroughly flushed	0·012	83
Rough cast-iron pipe: ordinary sewer pipes, laid under usual conditions: dressed masonry: brickwork, well laid and well jointed	0·013	77
Riveted and butt-jointed steel pipe—new.	0·014	71
Smooth dressed masonry or brickwork sewers, somewhat fouled or tuberculated	0·015	67
Riveted and butt-jointed steel pipe—2 years old	0·016	63
Rough ashlar masonry: good rubble masonry: rough and fouled brickwork sewers	0·017	59
Coarse rubble masonry: canals in firm compact gravel, or pitched with stones	0·020	50
Well-made earth canals in good alignment	0·0225	44
Canals, rivers, and watercourses, in ordinary condition and free from stones and weeds	0·025	40
Rivers and canals in earth, somewhat obstructed by stones and weeds	0·030	33
River sand canals with gravel beds in bad order, obstructed by vegetation—according to condition	0·035 to 0·040	29 to 25
Torrential streams, strewn with stones and other detritus	0·050	20

What is the velocity of the flow in the previous example and the discharge in cubic feet per second?

Substituting the value found for C,

$$v=C\sqrt{mi}=110\times\sqrt{0{\cdot}7118\times0{\cdot}00492}=6{\cdot}51 \text{ ft. per sec.}$$

Substituting the values of A and v,

$$Q=5{\cdot}7868\times6{\cdot}51=37{\cdot}67 \text{ cusecs.}$$

While the expression $v=C\sqrt{mi}$ is simple, the working out of values for C is a somewhat tedious procedure, but comprehensive tables are now available in engineers' handbooks, and these should be referred to.

Of other formulæ applicable to the present condition may be mentioned that published by Williams and Hazen, in which

$$v=1{\cdot}318km^{0{\cdot}63}i^{0{\cdot}54}.$$

The quantity 1·318 remains constant in all cases. Numerical values of the coefficient k for different kinds of channels are given in Table IB, the

TABLE IB.

Character of Channel or Conduit.	Observed Values of k.	Recommended Trial Values of k.
Composition-coated new cast-iron pipes	111 to 146	100
Tuberculated cast-iron pipes	16 „ 112	
Riveted steel pipes	97 „ 142	95
Wooden stave pipes	113 „ 129	120
Fire hose, rubber-lined	116 „ 140	
Masonry aqueducts	118 „ 145	120
Vitrified pipes	..	110
Brick sewers	102 to 141	100
Unplaned-plank aqueducts	113 „ 120	100
Rubble masonry	..	83
Earth channels	33 to 71	70

values in the third column being recommended by the authors of the formula for use in computations concerning the capacity of a proposed conduit or channel. To discover the inclination necessary to obtain a given velocity, the above formula is transformed to solve for i, becoming

$$i^{0\cdot54}=\frac{v}{1\cdot318km^{0\cdot63}},$$

from which

$$i=\sqrt[0\cdot54]{\frac{v}{1\cdot318km^{0\cdot63}}}.$$

The hydraulic mean depth depends on the size and shape of the water section in the conduit, and if these particulars are unknown it is impossible to discover the quantity m by a direct transformation of the formula. To make the desired calculations it is first necessary to express the hydraulic mean depth and cross-sectional area in terms of the breadth, depth, or diameter. For example, with a circular conduit running full, $m=0\cdot25d$ and $A=0\cdot7854d^2$. Now $v=Q\div A$; hence, substituting known values of m and A and placing in equality with each other the two values of v,

$$1\cdot318k(0\cdot25d)^{0\cdot63}i^{0\cdot54}=\frac{Q}{0\cdot7854d^2}.$$

Transposing,

$$0\cdot7854\times1\cdot318k(0\cdot25)^{0\cdot63}i^{0\cdot54}d^{2+0\cdot63}=Q,$$

and therefore, for a circular section running full,

$$d=\sqrt[2\cdot63]{\frac{Q}{0\cdot7854\times1\cdot318k(0\cdot25)^{0\cdot63}i^{0\cdot54}}}.$$

From this value of d, the value of m is readily found, since it is $0\cdot25d$.

Pipe Flow.—For a pipe running full, v in cubic feet per second is equal to

$$8\cdot025\sqrt{\frac{d}{f}\times i},$$

d being the diameter in feet and f the coefficient of friction.

Knowing the velocity, the discharge

$$Q=0{\cdot}785d^2v$$

and

$$i=\frac{fv^2}{64{\cdot}4d},$$

and assuming i to be more than $1000d$,

$$d=0{\cdot}4788\left(\frac{fQ^2}{i}\right)^{\frac{1}{5}}$$

while

$$f=\frac{64{\cdot}4d}{v^2}i.$$

f, as given above, only applies to clean pipes; those conveying sewage usually require f to be taken equal to twice the value.

Sewer Flow. Oval Section.—Somewhat different considerations enter into the calculation of flow in egg-shaped sewers. There are various forms adopted for the class of sewer, that shown in fig. 13 being the most usual.

The vertical and horizontal centre lines are set out, and, knowing the radius of the arch, it is made to start from the intersection of the two. The depth is then made equal to three times the radius, while the two distances $x\,x$ are made equal to twice the radius.

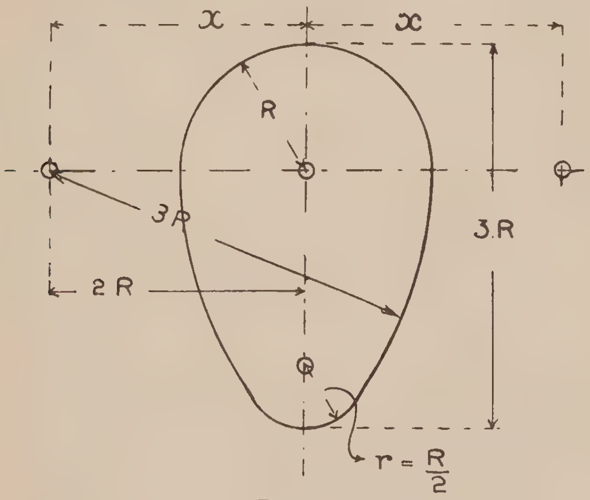


FIG. 13.

From these points circles are drawn as shown with radii equal to three times R, and the invert completed with a circle equal to $\frac{1}{2}$ R.

To calculate the discharge from such a sewer one requires the H.M.D. and the sectional area of the stream flowing therein. To calculate the former quantity by direct methods is a laborious procedure. To avoid this, predetermined coefficients are of use. These, as given in Molesworth's

TABLE II.

Height of Water in Egg-shaped Sewer in terms of Radius = R.	Corresponding Coefficient = K.	Height of Water in Egg-shaped Sewer in terms of Radius = R.	Corresponding Coefficient = K.
0·2	0·121	1·8	0·595
0·4	0·213	2·0	0·634
0·6	0·288	2·2	0·662
0·8	0·303	2·4	0·680
1·0	0·411	2·6	0·684
1·2	0·470	2·8	0·669
1·4	0·515	3·0	0·581
1·6	0·558		

TABLE III.

Height of Water in Circular Sewer in terms of Radius = R.	Corresponding Coefficient = K.	Height of Water in Circular Sewer in terms of Radius = R.	Corresponding Coefficient = K.
0·1	0·065	1·1	0·530
0·2	0·127	1·2	0·555
0·3	0·186	1·3	0·576
0·4	0·241	1·4	0·593
0·5	0·293	1·5	0·603
0·6	0·342	1·6	0·608
0·7	0·387	1·7	0·607
0·8	0·428	1·8	0·596
0·9	0·466	1·9	0·573
1·0 half full.	0·500	2·0 full.	0·5

pocket-book for various values of d (the depth of liquid flowing), are tabulated in Tables II. and III., and the

$$\text{H.M.D.} = RK.$$

For the area when full,

$$A = 1{\cdot}106d^2.$$

When two-thirds full, which is the usual calculation to make,

$$A = 0{\cdot}720d^2,$$

and

$$A = 0{\cdot}278d^2$$

when one-third full.

Example.—An egg-shaped sewer of 3 ft. × 4 ft. 6 in. is running two-thirds full, and the fall is 10 ft. per mile.

Referring to Tables II. and III., K=0·634, and

$$V=\frac{10}{11}\sqrt{1\cdot5\times0\cdot634\times10\times2}$$

$$=\frac{10}{11}\times\sqrt{19\cdot02}=\frac{10}{11}\times4\cdot359=3\cdot961 \text{ ft. per second.}$$

The wetted perimeter in such a sewer running two-thirds full is

$$2\cdot3899d,$$

while the whole perimeter is equal to

$$3\cdot961d.$$

The sectional area of the liquid is equal to 0·720×9=6·480 sq. ft.; therefore the discharging capacity is equal to 3·961×6·480=25·68 cub. ft. per second.

This may be shown to compare favourably with a 4-ft. diameter circular sewer running half full. Here the H.M.D.=half the radius=1.

$$V=\frac{10}{11}\sqrt{1\times2\times10}=\frac{10}{11}\sqrt{20}=\frac{10}{11}\times4\cdot47$$

=4·0636 ft. per second with a sectional area of 6·28 sq. ft. It will therefore be observed that the egg-shaped sewer does not present any special advantages when running two-thirds full over a circular one half full, these being the maximum capacities in practice. It is for small flows that the advantage is so apparent, because, whilst one must provide for removing a maximum quantity of flood water, yet it is necessary to remove, with equal facility, the smallest dry-weather flows at the times of minimum discharge, viz. about midnight. To show what a difference there is in the quantity flowing at different periods of the day, Tables IV. and V. were prepared by the writer from the results of actual gaugings. They give for the twenty-four hours of the day the percentage of the maximum flow. Table IV. tabulates results from a 5 ft. 6 in. egg-shaped sewer, and Table V. those from a 9-in. pipe sewer.

TABLE IV.—DISCHARGE OF EGG-SHAPED SEWER.

Time of Day.	Discharge Rate in Gallons per hour.	Time of Day.	Discharge Rate in Gallons per hour.
1 a.m.	23,410	1 p.m.	90,982
2	26,423	2	80,110
3	32,721	3	97,190
4	40,890	4	115,000
5	43,940	5	127,982
6	40,520	6	101,713
7	47,310	7	62,421
8	52,391	8	31,409
9	66,379	9	27,707
10	70,981	10	28,404
11	79,724	11	27,210
Midday, 12	105,314	Midnight, 12	24,727

TABLE V.—DISCHARGE OF SMALL PIPE SEWER.

Time of Day.	Discharge Rate in Gallons per hour.	Time of Day.	Discharge Rate in Gallons per hour.
1 a.m.	200	1 p.m.	9,000
2	101	2	11,200
3	127	3	7,500
4	40	4	6,400
5	41	5	9,700
6	4,200	6	10,200
7	7,000	7	4,100
8	7,500	8	2,100
9	6,200	9	120
10	7,100	10	241
11	14,000	11	71
Midday, 12	15,200	Midnight, 12	104

Investigating further the advantages of the egg-shaped sewer, consider it with only $3\frac{1}{2}$ in. of liquid on the invert. Referring to Table II., the value of $K=0\cdot121$.

$$\therefore\ \text{H.M.D.}=\frac{0\cdot121\times3}{2}=\frac{0\cdot363}{2}=0\cdot1815.$$

$$\therefore\ V=\frac{10}{11}\sqrt{0\cdot1815\times20}=\frac{10}{11}\times\sqrt{3\cdot63}=\frac{10}{11}\times1\cdot906=1\cdot732 \text{ ft. per second.}$$

Taking the 4-ft. circular sewer again with a velocity of 1·732 ft. per second,

$$h=\frac{\left(\frac{V}{\frac{10}{11}}\right)^2}{f}=\frac{\left(\frac{1\cdot732\times11}{10}\right)^2}{20}$$

$$=\frac{(1\cdot9052)^2}{20}=\frac{3\cdot715}{20}=0\cdot18575.$$

And to maintain this velocity in a circular sewer it would require 6 in. of liquid on the invert, which represents a considerably greater flow than the $3\frac{1}{2}$ in. in the egg-shaped sewer with an invert radius of 9 in.

Loss of Head in Pressure Pipe.—The principal function of a pressure pipe in a sewerage scheme is as a pumping main, and friction is an important factor, which may account for quite an appreciable amount of power being absorbed.

The loss of head by friction, or the head absorbed in the pipe by friction, and which has to be added to the static or pumping head, is proportional to

1. Length of pipe.
2. Roughness.
3. Square of the velocity.
4. Inversely as diameter of pipe.
5. It is quite *independent* of the pressure.

The use of pipes under pressure in a sewerage scheme is not usual, but it occurs in such cases as the rising pipe from a pumping-station or ejector or an inverted syphon, and very rarely in a gravitational sewer. A formula for the loss of head due to friction is as follows :—

$$H=\frac{G^2L}{(3D)^5},$$

where H=loss of head in feet.
G=gallons of liquid passing per minute.
L=length of pipe in yards.
D=diameter in inches.

As, however, the use of cast-iron pipes under pressure will, in this case, usually be in the form of a rising main from a pumping plant, there is a modification of the above equation which will give the loss of energy in foot-lb. This is a more useful quantity, as will be shown later.

Let H_i be this quantity.
l =length of pipe in feet.
V=velocity in feet per second.
d =diameter in feet.

Then

$$H_i=\frac{0{\cdot}0007lV^2}{d},$$

H_i denoting the loss of energy in foot-lb. for every *pound* of liquid passing through the pipe.

Measurement of Flow.—The foregoing discussion is directed to the use of formulæ for estimating the flow in a pipe or sewer, and by transposing such formulæ to estimate sizes for sewers to convey definite volumes where the available fall is known. The measurement of flow in channels and pipes is a necessary part of the civil engineer's business. Apart from commercial water meters, which have no significance in sewerage work, there are two principal methods of measuring the flow of liquid, viz.:

1. By a notch gauge.
2. Venturi tube.

The notch gauge, properly constructed, is accurate for all practical purposes of gauging the flow of sewers, streams, pump discharge, etc., and is a very useful and widely used appliance.

Its general construction is shown in figs. 14, 15, and 16. It is usually constructed of 2-in. planks; the actual sill may be a thin plate if desired, but is not absolutely necessary, as the edge may be straight or bevelled upstream or downstream. These considerations are governed by the coefficients used, based on the practical results obtained with particular forms of gauges. Bronze plates are better than iron ones, and those bevelled away from the flow have been proved to give the best results. The actual dimensions of the gauge are, of course, entirely governed by the amount of water likely to flow over it, which is usually determined from the drainage area supplying the stream in question.

The probable variation of flow must also be taken into account, because the gauge should be capable of recording both the maximum flood and the smallest dry-weather flow. Hence in the form of gauge shown there are two or more " notches " or divisions, the smaller quantities being confined to the smaller notches, where large floods are spread over the whole of the gauge. The construction of such gauges demands the utmost care if they are not to be destroyed by a sudden flood. The original channel must either be entirely diverted, or the gauge must be constructed one-half at a time, and be protected by a cofferdam. It is necessary to set it in a trench at least 2 ft. deep, and tailing into the sides of the stream at least this amount, but in the latter case concrete piers will be found much more serviceable, and well worth the small extra expense. The trench must be filled with well-puddled clay to the depth stated, or, if there is any chance of the head of water being great enough to blow it out, deeper. On the lower side a stone "apron," in the form of dry pitched rubble, is necessary, 18 in. deep, as shown. Piles would be driven as shown, and struts placed thereto as an additional precaution against failure. When the bottom of the river is sand or gravel, puddling fails in its purpose, and sheet piping, about 3 in. thick, is then resorted to instead, because, even if the puddle did stand firm, there would be a likelihood of the water finding a way out underneath it. It may be stated that the size of such a gauge is limited, 20 ft. being about the maximum convenient length. Again, in such a form of gauge it is inadvisable to subject it to a greater head than 5 ft. ; that is, 3 ft. below the notch and 2 ft. above it. Of course, in sewerage schemes, it is unlikely any gauge will reach these dimensions at all. They are usually confined to much smaller dimensions, as indicated further on. Having set up a gauge in accordance with the foregoing principles, some means of reading the depth of water flowing over it must be devised, in order to arrive at an accurate estimate of the quantity of water passing. A foot-rule is obviously quite inadmissible, even if the actual depth in the notch could be recorded in this way. Fig. 17 represents in an exaggerated way what takes place when water is flowing over such a gauge. Ax indicates the surface of still water, the " head " H on the sill is equal to Az. Obviously,

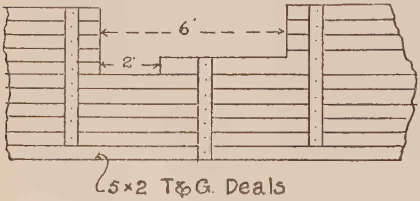


FIG. 14.

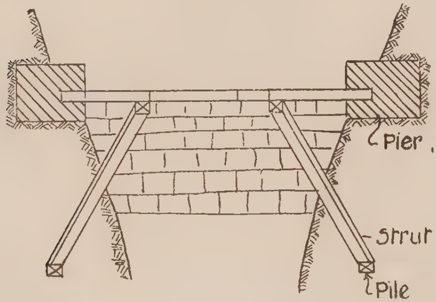


FIG. 15.

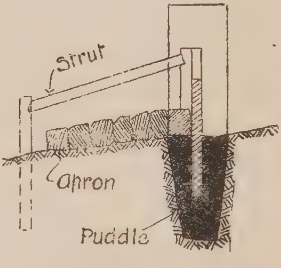


FIG. 16.

then, H is the value required, and not $h=yz$. It will also be obvious that any velocity of approach will be detrimental to calculations, and it must either be taken into account or reduced to an inappreciable quantity by so widening the stream above the gauge that the sectional area of the volume flowing over the weir is not more than $\frac{1}{5}$ that of the supplying channel. The method of finding the depth H is as follows: Fig. 18 shows a hook gauge set some distance upstream from the gauge. An empirical rule is to make the distance x equal to at least twice the width of the gauge. The hook gauge is shown in figs. 19 and 20, and is constructed as follows: AB is a round brass rod, to which is fixed a brass wire hook sharpened at C. D is a tube of brass, fixed firmly to the supporting framework, in which AB slides. On AB is a scale of inches and $\frac{1}{10}$ths, while D has a Vernier for accurate measurements. The important point in setting this piece of the work is to have a zero reading on the scale when the point of the hook is *dead level* with the lowermost sill of the gauge. When water is flowing over the gauge the hook is gently raised so as to form a small "pimple" on the water surface.

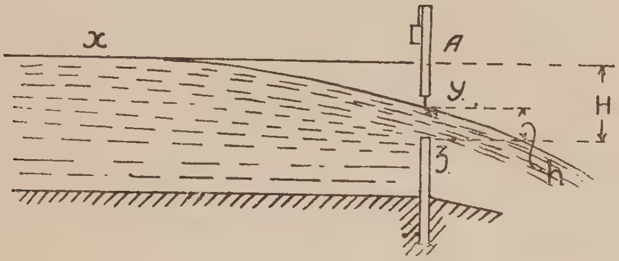


FIG. 17.

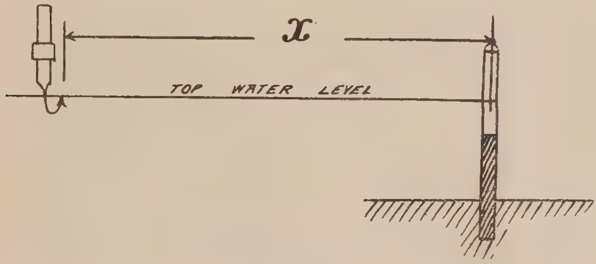


FIG. 18.

Knowing, then, the depth of water flowing over the gauge, and also the size of the notch, the discharge therefrom can be calculated. The actual discharge is always less than the theoretical discharge of any weir, due to end and side contractions, which are, however, materially reduced if the ratio of the areas of water flowing over the gauge and in the supply channel is kept down within the prescribed limit. The coefficient of contraction will then have a value of about 0·60, slightly more or less, according as the depth of water on the weir is greater or less than 6 in.

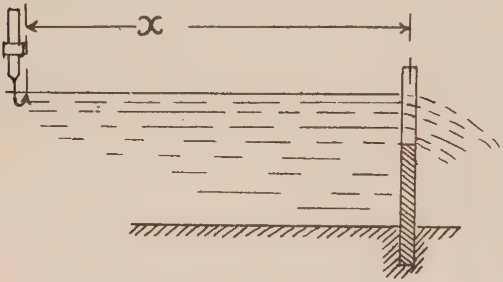


FIG. 19.

Let l be the length of the weir in feet and d the depth of water thereon.

Let Q=the discharge in cubic feet per minute.

Then

$$Q=\tfrac{2}{3}\sqrt{2g}\times c\times l\times d\times\sqrt{d}$$
$$=3{\cdot}25ld\sqrt{d}$$
$$=3{\cdot}25l\sqrt{d}^{2}.$$

For general use, roughly made gauges are employed. For better-class work, and iron or bronze plates, (thin) or bevelled off on the downstream side are preferable.

The results of the experiments carried on by Mr Blackwell on the Kennet and Avon Canal are available, the values of c being tabulated in Table VI.

The constants are arrived at in the following manner :—

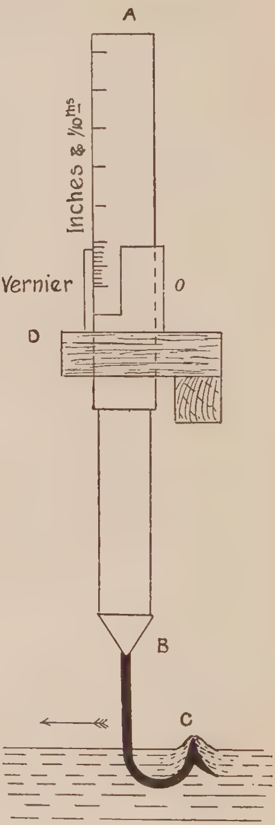


FIG. 20.

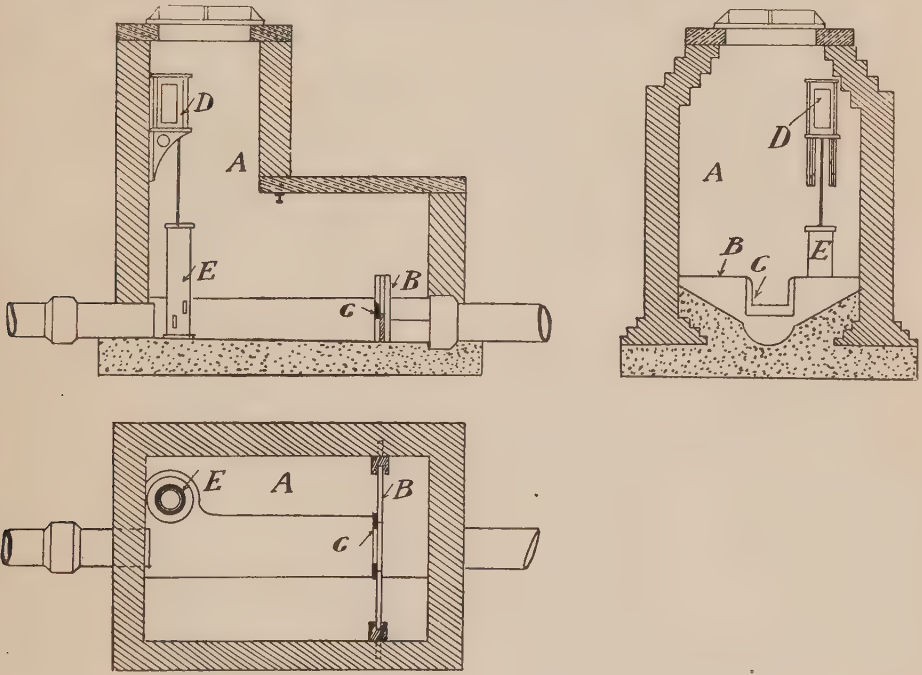
TABLE VI.—VALUES OF *c* DERIVED FROM MR BLACKWELL'S EXPERIMENTS ON THE KENNET AND AVON CANAL, FOR 2-IN. PLANKS AND $\frac{1}{16}$-IN. IRON PLATES.

Depths.	Values of c.	
	2-in. Planks.	$\frac{1}{16}$-in. Plates.
In.		
1	3·50	5·72
2	4·25	5·70
3	4·44	4·91
4	4·44	4·90
5	4·62	4·83
6	4·57	4·57
7	4·61	
8	4·68	4·48
9	4·44	4·08

It was pointed out that the velocity of a falling body in feet per second in terms of the head is $8\sqrt{h}$, which formula applies to the lowermost particles of water passing over the weir. Taking the mean as $\frac{2}{3}$ of this, the velocity $=5\frac{1}{3}\sqrt{h}$. But considering the coefficient of contraction referred to, there is only $\frac{5}{8}$ of this value effective, which reduces it to $3\frac{1}{3}\sqrt{h^3}$ *per foot length of gauge.* It is usually convenient to measure the depth in inches. Hence dividing $3\frac{1}{3}$ by $\sqrt{12^3}$, taking the quantity in cubic feet per minute,

$$\frac{3\frac{1}{3}\times 60}{41{\cdot}56}=4{\cdot}81,$$

which is the constant multiplier for the normal condition of a weir.



FIGS. 21, 22, and 23.

In fact, 4·80 may be taken as a very fair average constant for a thin plate weir; but when this is not the case, and the sill has appreciable thickness, then the conditions are altered. The reason for this is that there is a diminution of depth on the outer edge, which is caused by the retardation of flow over the sill of the weir, which increases with the thickness of that weir. This is the case with sewage flowing over a long weir, bullnose in shape, and made of ashlar, into a series of sedimentation tanks. The foregoing value of c, viz. 4·80, will then be too large; but the previous equation may be used, provided d is not greater than 24 in., which is hardly likely to be the case; then the value of c will be 3·25.

The principal use, however, to which weirs of the temporary nature described would be put in a sewerage scheme would be to gauge sewers, in which case, being small, they can be constructed with accuracy. They can be conveniently placed in a manhole as shown in figs. 21, 22, and 23. In this case, however, the flow will be considerably less than in the case of a small river, and the ordinary hook gauge shown in fig. 21 will not give sufficiently accurate results. As a substitute there is the float gauge. In figs. 21, 22, and 23, B is the wood gauge, C is a bronze plate, E is the float gauge, and D the recording gear thereof. In fig. 24 this gear is illustrated on a larger scale. For such gaugings this instrument is a very simple and valuable piece of mechanism, because, being provided with a clockwork motion, it will give a continuous record of the depths over any desired period of time. The instrument shown is made by the Palatine Engineering Co., who provide, instead of the ordinary printed diagrams, plain ones, on which the instrument draws its own zero line, previously set to the exact level of the weir sill, at the same time as the fluctuations of flow are being traced out on the diagram.

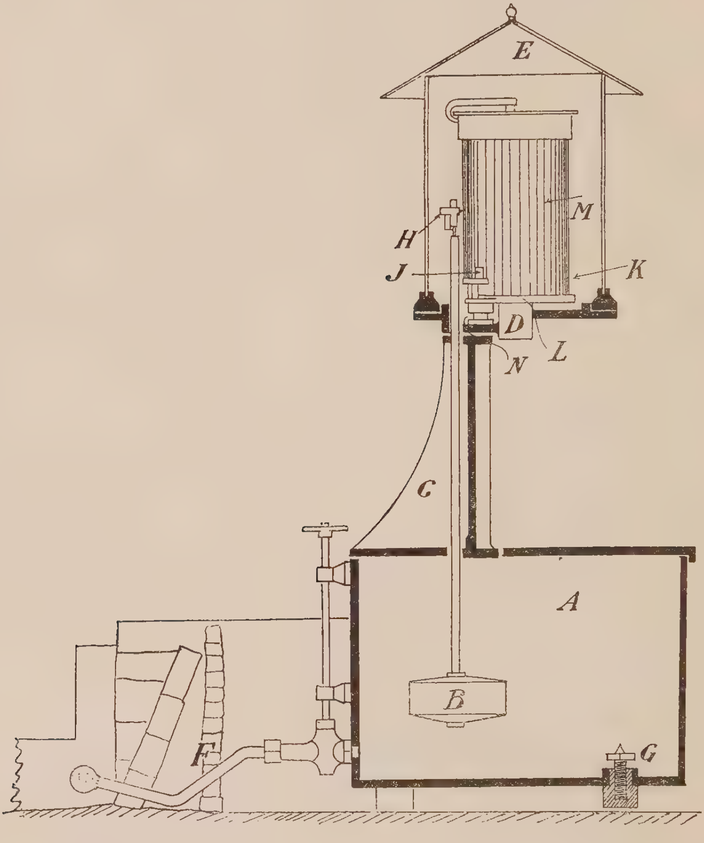


FIG. 24.

The method of fixing and setting is as follows :—

Having adjusted the point gauge G inside tank to about its middle position, set the tank A so that the point G is about level with the sill of the weir gauge ; connect the pipe F, and when the tank is in position and carefully set up with a spirit-level, ram up so that it cannot be moved ; open the cock full and allow water to pass into the tank. Measure the height flowing over the weir, and now set the zero point G to the same level as the sill. Now close the cock and empty the water out of the tank by bailing or syphon until the water reaches the level of the zero point. The float pen H will now be marking a certain level on the diagram, and this is the zero level, and the zero pen must now be set to this line. The cock can now be opened and kept open, and when the clock is wound the instrument will commence recording.

The instrument illustrated in fig. 24 is solely for the purpose of recording the depth of water on the sill of the gauge, and for this purpose it is admittedly very useful.

The Lea Recorder Co. have recently brought out an instrument of a more comprehensive nature.

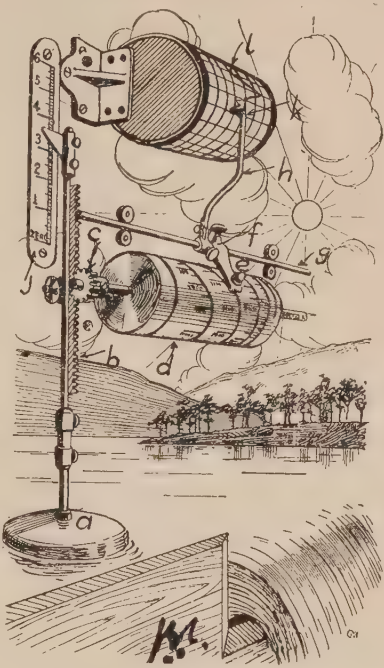


FIG. 25.

Illustrated in fig. 25, it will be seen to combine considerable ingenuity with extreme accuracy. There is the essential float *a*, the movement of which is communicated by rack *b* to pinion *c* on the axle of spiral drum *d*. Drum *d* is virtually a large screw with a gradually increasing pitch. Pin *e* on the end of saddle arm *f* engages with this thread, and thus imparts a lateral motion to slide bar *g*, carrying pen arm *h*. At one end of the drum the pitch of the thread is zero, and at the other end it is maximum, and this increasing pitch is made to correspond exactly with the increasing flow of the water over the notch according to the formula used. As pin *e*, therefore, moves along this groove it forms a magnified indication of the *rate* of flow. Rate of flow, however, is more or less indefinite information, but by means of an integrator total flow may be recorded. This integrator is attached to bar *g*, and moves with it in direct proportion to the rate of flow.

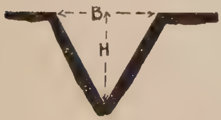


FIG. 26.

The V Notch.—The rectangular notch is essentially suited to the measurement of large volumes of water. The V notch (fig. 26) is a useful appliance for dealing with smaller flows, such as pump discharges. The rectangular V notch with a depth of water H has a discharge in cubic feet per minute equal to

$$Q=c(H)^{\frac{5}{2}},\ c \text{ being equal to } 0{\cdot}30.$$

To record automatically the flow, however, presents the difficulty of the small rise of the float for the larger volumes, so that the scale, if graduated in equal increments of flow, will be very open at the beginning and very crowded in the upper portion. Of various arrangements made use of to overcome this difficulty may be mentioned the rheograph, a device arranged to read flow in gallons per hour against a quadrant scale, in addition to recording the flow on a chart attached to a time drum.

Flow through Orifices.—Another way of measuring the flow of liquid is by means of a submerged rectangular opening, as shown in fig. 27. Let l be the length of the opening or slot in feet, and h_1 and h_2 the distances as shown on the diagram. Let h be the mean of h_1 and h_2.

Then

$$Q = cld\sqrt{2gh},$$

c being as in Table VII.

TABLE VII.—VALUES OF c.

Head over Centre of Orifice.	$l=2$ ft., $d=1$ ft.	$l=2$ ft., $d=6$ in.	$l=1$ ft., $d=1$ ft.	$l=1$ ft., $d=6$ in.	$l=1$ ft., $d=3$ in.	$l=9$ in., $d=9$ in.	$l=6$ in., $d=6$ in.	$l=3$ in., $d=3$ in.
Ft.								
0·5	0·60	0·61	0·60	0·61	0·63	0·60	0·60	0·60
1	0·60	0·62	0·60	0·62	0·63	0·60	0·60	0·60
2	0·60	0·62	0·60	0·62	0·63	0·60	0·60	0·60
3	0·60	0·62	0·60	0·62	0·63	0·60	0·60	0·60
4	0·60	0·61	0·60	0·61	0·62	0·60	0·60	0·60
5	0·60	0·61	0·60	0·61	0·62	0·60	0·60	0·60
6	0·60	0·61	0·60	0·61	0·62	0·60	0·60	0·60
7	0·60	0·61	0·60	0·61	0·61	0·60	0·60	0·60
8	0·60	0·61	0·60	0·60	0·61	0·60	0·60	0·60
9	0·60	0·61	0·60	0·60	0·60	0·60	0·60	0·60
10	0·60	0·61	0·60	0·60	0·60	0·60	0·60	0·60
20	0·60	0·60	0·60	0·60	0·60	0·60	0·60	0·60

If the orifice is submerged, that is, has both sides flooded, the difference of level on either side $=h$ and $c=0{\cdot}67$, and the above equation will then hold good. Continuous records will, of course, require to be kept of these levels, for which has been devised a very ingenious apparatus, fully described in *Waterworks Engineering* by Messrs. Tudsbery and Brightmore, p. 82.

A submerged opening need not of necessity be rectangular; a circular one will give accurate results. The hole must be accurately formed in a thin bronze plate.

Let A be its area in square feet, and H the distance from centre of the orifice to top water-level in feet. Then Q in cubic feet per second may be found with accuracy sufficient for ordinary purposes by the equation

$$Q = 0{\cdot}62A\sqrt{2gH}.$$

Leap Weirs.—In a stream of water having a free flow over a weir or through an opening, the flow is due to the "head" of water above that opening. There are two forces acting on the resulting jet, viz. a horizontal one, due to the force of the water issuing from the jet, and a vertical one, due to the action of gravity on that jet. If these were uniform forces, every particle of water in the jet would move in a straight line, the direction of which would be governed by the magnitude thereof. But in this case the two forces are not uniform, that due to gravity being a constantly increasing one, as already pointed out. That is, if t=time in seconds, the space each particle of water will fall

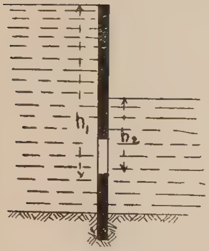


FIG. 27.

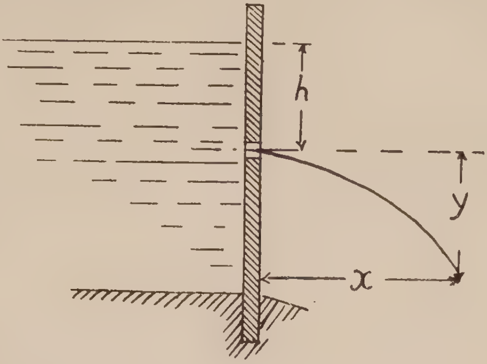


FIG. 28.

$$=y=\tfrac{1}{2}gt^2.$$

Now let x=the force of the issuing jet due to the head h, as shown in fig. 28.

Then, because

$$h=\frac{v^2}{2g}$$

and

$$y^2=\frac{v^2}{2g}0{\cdot}4x,$$

$$y^2=4xh,$$

proving that y^2 bears a constant relation to x, which also proves that the path of the water assumes a parabolic curve, which is a very important point to bear in mind. Of course, for water flowing over a sill or through an orifice, the form of curve it takes matters little under ordinary circumstances; but when considering what are known as leap weirs it is very important. For instance, fig. 29 is a diagram of a parabolic leap weir. Sewage flows down a sewer, as shown, to the leap weir. So long as the quantity does not exceed six times the dry-weather flow or other predetermined quantity, it will tumble over the weir into the outfall sewer below. If the quantity increases, however, the depth of water will increase;

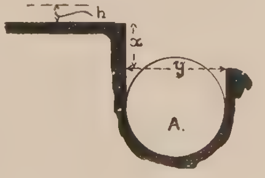


FIG. 29.

consequently also the value for h previously given What is the result ?—x will be kept constant (fig. 28) by the predetermined size of the weir, while y will increase, due to the greater value of h; and the water, instead of tumbling into the outfall sewer, will be deflected wholly or partially over the lip into the storm sewer. Hence, knowing the curve will be parabolic, one can deduce a very simple equation to find the proper dimension of the weir. The volume of sewage to pass to the purification works is estimated; knowing this, and the size and inclination of the sewer, the depth of water over the invert can be calculated.

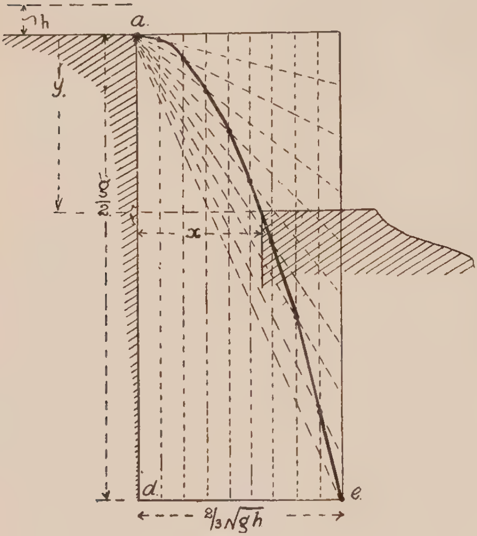


FIG. 30.

The mean effective depth will then be $\frac{4}{9}$ of this value. As $y^2=4xh$, the value of

$$y=\sqrt{4xh}.$$

These values can also be attained graphically if a diagram such as that in fig. 30 is drawn on squared paper to a large scale, the values of x and y being as follows:—

$$y=\tfrac{2}{3}\sqrt{2gh},$$

$$x=\tfrac{9}{16}\frac{y^2}{h}.$$

Venturi Tubes.—While the Venturi is essentially a water meter for dealing with large flows, it has a certain significance in sewerage work as a means of measuring pump discharges on the one hand and flow through pipes and open channels on the other.

In the latter connection special types are available, as will be pointed out, and quite a recent introduction, which is certainly applicable to sewerage work, is the formation of the tubes in concrete, the throats only of bronze. This method of construction was adopted at the Littleton Queen Mary Reservoir of the Metropolitan Water Board.

For the information of the reader it might be mentioned that the Venturi system of water measurement is under the control, so far as Britain and the Colonies are concerned, of Messrs Geo. Kent & Co. of Luton. The Venturi is one of several measuring instruments for dealing with both water and gas, and, incidentally, compressed air, which operates upon the pressure difference principle.

Briefly, without going into deep theory, this principle acts as follows. Between points A and B (fig. 31) in the pipe line are a short reducer a, the throat b, and the increaser c, the latter being longer than a. Two small pipes are led from d and e to the recording mechanism. The velocity in the throat is greater than that in the pipe, and the pressure in pipe e is less than that in pipe d. This pressure difference is directly proportional to the amount of water flowing, and is made use of for recording it. In the main this P.D. acts on a mercury column or manometer which, acting on floats connected to a gear train combined with cams, constitutes the recorder. The instrument in practice is quite simple and extremely accurate, although calling for very precise workmanship. Venturi meters now figure in most up-to-date pumping plants.

The Venturi principle is of sufficient interest to warrant a short explanation of it. The diagram in fig. 32 shows the mercury column with its connecting pipes to the throat and upstream end. These pipes are full of water, and the value of h' in feet is equal to 12·59 times h; d, it will be seen, is about $\frac{1}{3}$ D, and the area A is that at D and a the area at d. With c a coefficient equal to 0·99, the quantity which passes is directly dependent upon h' the Venturi head, which, as stated, equals 12·59 times h the head of mercury in column a, and is equal to

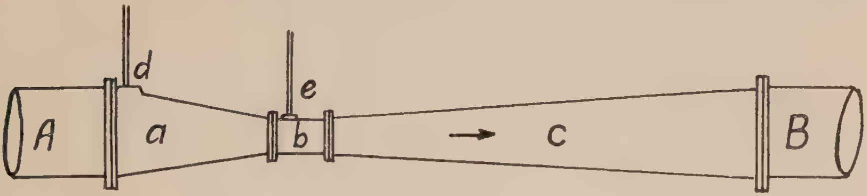


FIG. 31.

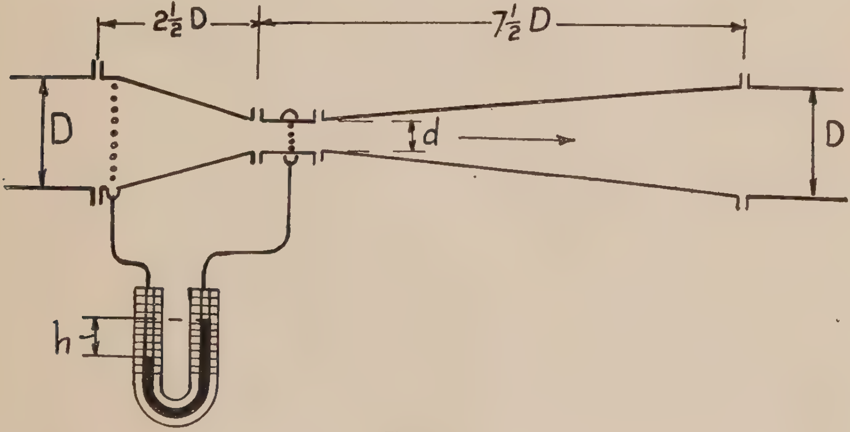


FIG. 32.

$$Q = cAa\sqrt{\frac{2gh}{A^2 - a^2}} \text{ in cubic feet per second.}$$

The proportions given for the length of the diminishing and expanding pieces are those usually adopted in practice.

Control Gear.—The Venturi principle has quite a number of applications in hydraulic engineering. It may be made use of, for instance, for controlling the injection of chemicals in sewage treatment plants, the amount of chemical being thus strictly proportioned to the flow.

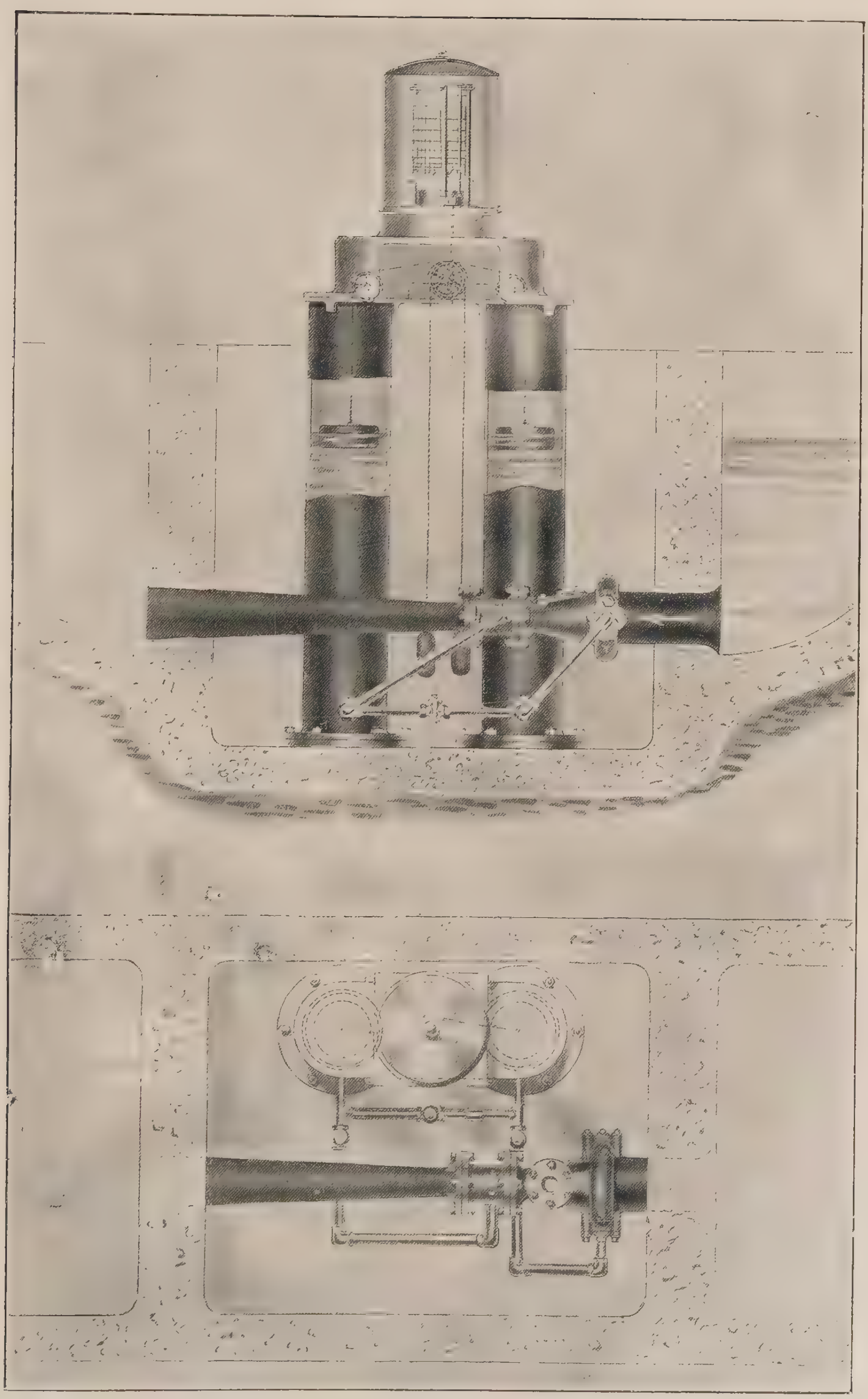
For controlling the rate of flow of water there is also an arrangement which virtually consists of a balanced disc valve. The amount which this disc valve is permitted at any time to be open is controlled by a Venturi, through which the liquid passes.

The Venturi in Sewerage Work.—In the measurement of sewage, whether crude or treated, the Venturi meter, from its valuable feature of having no moving part in contact with the passing fluid, has unique capabilities. It is immaterial what quantity of solid matter may be passing, there being no mechanism to clog or passages to obstruct. Knowledge of quantity in sewage schemes is often of considerable value; one purpose in particular is well served by measurement—that is, where lime or other precipitants have to be used. As the exact quantity of chemical to be added can only be known when the volume of sewage to be treated is also known, with the Venturi meter the total quantity passed in any hour into the settling tank will determine the amount of precipitant used for that hour. The recorder can be fixed in the liming house, so that the men in charge of the work can see from time to time exactly what is required: in this way efficiency and economy with precipitation would at once be attained. Slight modifications are made on the meter when used for this purpose: means are provided to keep the pressure holes clear, and small oil cylinders intervene between the tube and recorder to prevent the access of any sewage to the latter.

Figs. 33 and 34 show a Venturi applied to the measurement of liquid flowing in an open channel. Water columns are used in place of mercury.

Retaining Walls Subject to Water Pressure.—The depth of liquid sustained by the walls of any tank dealing with sewage is not usually very great, but it is necessary to investigate the stability of walls under such conditions. Water standing in a vessel or tank to any depth exerts a pressure at right angles to the force acting on it. This force has already been pointed out to be gravity which acts vertically; hence the pressures acting on the sides of the enclosing vessel act at right angles to the vertical, viz. horizontally. Now it is a known fact that in a fluid at rest there can be no shearing forces. It is also an equally established law that friction is always brought about as a shearing stress; hence with a liquid, such as water, at rest, there are no frictional forces tending to preserve the equilibrium of any portion of it. Consider a column of water with a base 1 ft. sq. Water in practical calculations is considered to weigh 62½ lb. to the cubic foot. Hence for every foot in height of the column the pressure of water will be 62½ lb. But on each vertical side of this column there will also be stresses always perpendicular to the side. But the shape of a tank holding liquid has no influence whatever on the pressure on the bottom. It is very important to understand this thoroughly, because it is a common error of students to suppose that the weight of water in the tank will give the pressure on the bottom.

In figs. 35 and 36 the pressures on the bottom of the two tanks are identical, although the weight of water in one is practically three times that in the other. Provided that the tanks are the same length, the pressures per unit of area are the same in both cases. But on the sides the pressure is everywhere perpendicular to the sides. Hence it is that at a given depth *h* the stress set up on any plane at that depth, whether horizontal, vertical,



Figs. 33 and 34.

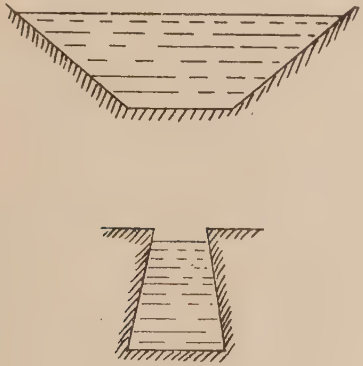
or inclined, is proportional to that depth *h*—that is

$$p = wh;$$

if a=the area of the plane in question in square feet and the plane is horizontal, the total pressure

$$p = wah.$$

The resultant pressure which acts on an immersed horizontal area always acts at the centre of that area; with a vertical one, however, that is not the case; in such case there is a certain point at which all the resultant pressure is supposed to be concentrated; it is always $\frac{2}{3}$ of the distance *h*, or the distance between top water-level and the bottom of the tank. With this consideration in mind, one can investigate the case of walls subject to water pressure. In sewerage works such calculations are of a simple character, being usually confined to the walls of precipitating tanks, in which the least economical thickness will often be more than that demanded for equilibrium under the pressure of the liquid with which they are filled. In waterworks engineering, however, the calculation becomes more complicated in order to obtain a section of wall or dam which will be the least extravagant of materials, and yet be safe against overturning under all conditions.


FIGS. 35 and 36.

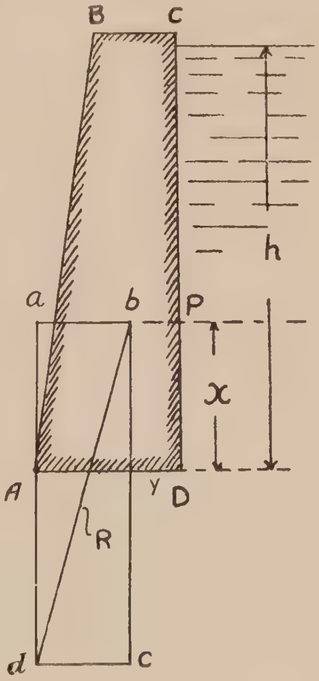


FIG. 37.

Considering fig. 37. ABCD is the proposed section of the wall of a concrete tank. Will it be safe when the liquid stands to a maximum depth *h*? In such calculations it is usual to consider a length of the wall equal to 1 ft. P is the centre of pressure, PD being equal to $\frac{1}{3}h$.

Let p be the unit pressure on the side of the wall, then the wall is subject to an overturning moment:

$$=p=\tfrac{1}{2}wh^2x.$$

To balance this there must be a resisting moment, which is supplied by the weight of the wall itself=W, which acts through the centre of gravity, a perpendicular line passing through which is at a distance y from the inner face. Hence, for equilibrium, Px must be equal to or less than Wy. The thickness of the walls of sewage tanks will usually be 9 in., 12 in., 15 in., or more, according to circumstances; but there is a simple formula for getting the exact thickness, which for brick walls can then be measured to a convenient multiple of the dimensions of the bricks used, that is $\frac{1}{2}$, 1, or $1\frac{1}{2}$ bricks, and so on, viz.:

$$T=0{\cdot}7H \tan\frac{a}{2}\sqrt{\frac{w}{W}},$$

in which T = the *mean* thickness of the wall in the same units as H the head of water, w being equal to 62·5, and W the weight per cubic foot of the wall in question. The value $\tan\frac{a}{2}$ has certain predetermined values for the formula, which is from Hurst's *Tables*. For water it is equal to 1. Earth retaining-walls may be treated in precisely the same way, or, if great refinement is required, the earth pressure due to the earth backing of the tank walls (if any) may be found, and the supporting moment so found may be sufficient to warrant a reduction of the thickness of the wall, although such calculations would hardly be gone into by practical engineers. Taking a practical case. Required the thickness of the walls of a tank made of concrete. Head of water 10 ft.

$$T=0{\cdot}7\times10\times1\times\sqrt{\frac{62{\cdot}5}{125}}=7{\cdot}0\times\sqrt{0{\cdot}5}=7{\cdot}0\times0{\cdot}225=1{\cdot}561=\text{say } 18 \text{ in.}$$

This may be tested graphically. Referring to fig. 37, the mean thickness is 18 in. The batter of the wall on the outer face may be sloping within reasonable limits provided a mean thickness = T is maintained, but the formula in question provides for a vertical inner face. Draw a section of the wall to a large scale, divide the base into three parts, and drop a perpendicular through the centre of gravity of the wall. Draw a horizontal line through the point P, calculate the weight of the wall in lb., and set it off to a suitable scale = bc; calculate the value $\frac{1}{2}wh^2$, and set it off to the same scale as $bc=ab$; complete the rectangle, and draw the resultant R. If R passes through the middle third of the base it is safe; if in the outer third, the wall will fail by overturning; if in the inner third, there is a waste of material. This mode of construction is well known and need not be further described; it gives accurate results, but they depend largely upon the scale of the diagram, which must be *large*. The above equation may be used for walls retaining earth, provided the top thereof is always level with the top of the wall. When this is not so, the wall becomes what is known as a *surcharged revetment*, in which case fig. 38 should be referred to, and instead of H the value H_1 used, found by setting off D = H on the slope of the earth backing. Under these circumstances $\tan\frac{a}{2}$ will no longer be unity, but will vary with the quality of the earth backing, according as a, the angle of repose, varies.

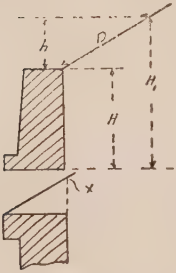


FIG. 38.

In Table VIII. some properties of the various qualities of earth met with in practice are given. Fig. 39 shows a graphical construction applicable to any form of retaining-wall, the angle of repose being taken as 30° with the horizontal, viz. =90°—30°=60°, as given in Table VIII. GD is what is termed the line of rupture, and BDG is the wedge of earth which is considered as providing active pressure on the wall. Considering 1 ft. length of the wall, calculate the weight of this wedge of earth at 112 lb. per foot cube. Set off KD=$\frac{1}{3}$DB, and to the scale of lb. adopted set off HK=weight of this wedge of earth, making KHJ=the angle of repose, viz. 30°, produced to meet a line drawn from K perpendicular to BD. JK will then denote to scale the horizontal thrust on BD due to the wedge of earth. Now find the centre of gravity of the wall. As the wall is not rectangular in cross section, the following construction will be useful for this purpose. On AB produced on either side set off x, x equal to CD, and likewise on CD produced set off y, y=AB. Draw the diagonal lines as shown, and G_1 the intersection is the centre of gravity of the wall. From it drop a perpendicular, making MP the weight of the wall at 130 lb. per foot cube, in this case =3920 lb. Complete the parallelogram and draw MO. If, then, MO passes within the middle third of the base of the wall it is safe. So much, then, for the pressure of earth and water upon walls.

TABLE VIII.

Nature of Soil.	Angle of Slope.		Weight per cubic foot.	Value of tan $\frac{a}{2}$.
			Lb.	
Gravel . . .	40°	Slope with horizontal	112	0·510
Dry sand . . .	38°		92	0·554
Sand	22°		116	
Vegetable earth . .	28°		83	0·414
Compact " . .	50°		100	0·466
Shingle . . .	39°		141	0·512
Rubble . . .	45°		153	
Clay (well drained) .	45°		112	
Wet clay . . .	16°		124	0·677
Water	90°	Slope with vertical	62·5	1·00
Excavated earth . .	56°		79	0·532
Gravel and sand . .	52°		115	0·488

Flap Valves.—The same conditions arise when a flap valve is subject to fluid pressure; but it may occur that it is not free from pressure on one side, but is as shown in fig. 40. In this case the total pressure on the gate

$$p=h_1^2-h_2^2\left(\frac{bw}{2}\right)$$

when b the width of the gate and $w=62\frac{1}{2}$ lb. But the centre of pressure is no longer $\frac{1}{3}$ the way up the gate, but at a distance from the base equal to

$$\frac{\frac{1}{3}(h_1^3-h_2^3)}{h_1^2-h_2^2},$$

and from this expression may be found the position of the hinge on a flood gate which is required to open when the water reaches a certain height.

For instance, a numerical example will illustrate this. In fig. 41 is assumed a drainage canal in which it is required to maintain a constant depth of 5 ft. over the sluice sill, while the level in the lower canal or tail water is 2 ft. above the same.

A teak sluice or gate 18 in. deep and 4 ft. wide is hinged as shown. Assuming the weight of this gate is negligible, to what extent must it be loaded to maintain the level of 5 ft. in the upper canal?

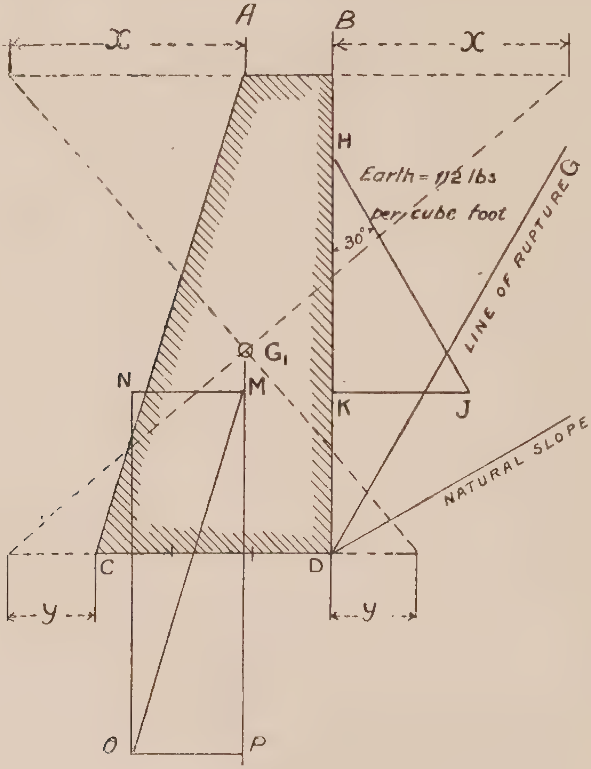


Fig. 39.

Using the above equations, the pressure on the gate is

$$5^2-2^2\left(\frac{4\times 62{\cdot}5}{2}\right)=25-4\times 125{\cdot}0=21\times 125{\cdot}0=2625 \text{ lb.},$$

while the centre of pressure is

$$\frac{1}{3}\frac{(125-64)}{25-4}=\frac{\frac{1}{3}\times 61}{21}=\frac{20{\cdot}333}{21}=\frac{6{\cdot}777}{7}$$

$=0{\cdot}9682$ ft. from the base of the sluice.

The sluice being 18 in. deep, there is a clockwise moment due to the water equal to $2625\times 0{\cdot}968-1{\cdot}5=2625\times 0{\cdot}532=1396{\cdot}5$ lb.-ft. It is necessary to provide, therefore, by means of weighted levers, an anticlockwise moment equal to this. Say 2 levers 3 ft. long are attached to the gate, 1396·5÷3=465·5 lb.÷2 (levers)=232·75 lb.; but as these weights will be under water, one must add $\frac{1}{7}$=232·75+33·25=266·00 lb., being the weight of iron required to act at a distance of 3 ft. from the sluice gate, in order that it may just begin to lift when the depth of water in the upper canal is 5 ft.

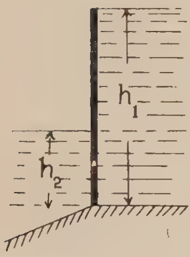


Fig. 40.

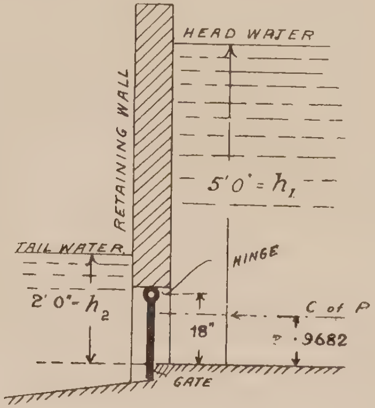


Fig. 41.

While a good deal more could be written upon the subject of practical hydraulics, the foregoing chapter treats of most of the problems which concern the drainage engineer. In the next chapter examples will be given of practical calculation which involve the application of the principles set forth.

CHAPTER III.

PRACTICAL CALCULATIONS IN REFERENCE TO THE DESIGN OF SEWERAGE WORKS.

In this chapter it will be shown how the principles in the previous one are put to practical use in designing sewerage schemes, but before doing so it will be well to consider what are the general effects of rainfall, which is a factor in all drainage schemes. In respect to this question, each country requires special consideration; in foreign countries, especially tropical and semitropical ones, the conditions of the rainfall are very different to those in the British Isles. Those who contemplate this class of work in such countries would do well by thoroughly acquainting themselves with the local conditions before proceeding, and making all necessary observations, in the event of no reliable statistics extending over a number of years being forthcoming.

Rainfall.—In Britain and Western Europe the chief source of rainfall is the Atlantic ocean: the watery vapour generated by the sun in hot areas is blown over by the prevailing westerly winds and condensed by the hills, with the result that rain is precipitated in large quantities on the high ground of mountain ranges. Much of the vapour will, of course, pass over the hills to the leeward side, some will also pass through the natural gaps in the hills and precipitate its moisture on this side. Above the altitude of about 2000 ft. the rainfall decreases. In England the gauging of rainfall does not provide much work for the civil engineer, by reason of the existing records being very full and of proved accuracy. Symons' *British Rainfall*, continued by Dr Mill, is the standard work on the subject, and is the record of long and persistent work on the part of these authors and their coadjutors. The rainfall maps issued by the River Pollutions Commissioners also provide much valuable information. The Ordnance Survey Office have also issued a similar map, entitled *Map of Rivers and Catchment Basins*.

Regarding the necessity for accuracy in these records, Mr Slagg, in his *Water Engineering*, very aptly says: "It is only by patient attention to and collection of observations on the rainfall in various parts of a country that data can be arrived at upon which to base calculations of what quantity of water may be expected to be derived from any particular source in any given locality. All atmospheric phenomena are most intricate in their relations to and effect upon the land: nothing but the most patient study of observed facts can determine anything worthy of being relied upon in practice."

As will be pointed out when considering gases and vapours under *Sewer Ventilation*, warm air is capable of holding more moisture than cold; but atmospheric air is never free from vapour, even on the coldest days. Air, however, can only hold a certain quantity of moisture, viz. up to the saturation point, and this point is governed by the temperature of the air. In our English climate 1·5 per cent. is the usual percentage of moisture present.

Roughly, on an average the rainfall in England is 40–50 in. per annum on the West Coast; it, however, may be as much as 75 in., 100 in., or even more at places, while on the East the rainfall is rarely over 25 in. per annum, the South Coast having a mean between the two of about 35 in. This only applies generally, the rainfall in every place varying greatly from year to year, and it is usually the *average* rainfall which principally concerns the engineer. This is a matter of easy calculation when records extend over a number of years, say for more than twenty years. When this is not the case, or some of the records are doubtful in accuracy, there are methods of arriving at this average with tolerable correctness. It is an established fact that if, from a series of records, the three *consecutively* driest years be taken *plus* $\frac{1}{6}$, the result will be equal to (within a fraction of an inch) the average of the whole series. This has been termed by the late Mr Hawkesley, the great waterworks authority, *the law of the minimum*, while four very important conclusions were arrived at by Mr Symons, as follows:—

1. The wettest year will have a rainfall of nearly half as much again as the mean.
2. The driest year will have $\frac{1}{3}$ less than the mean.
3. The driest two consecutive years will each have $\frac{1}{4}$ less than the mean.
4. The driest three consecutive years will each have a fall of $\frac{1}{5}$ less than the mean.
5. At places having a large average rainfall, the extremes of wetness and dryness will be less in proportion than at places where the average rainfall is small.

The amount of rainfall lost by evaporation and percolation is also of direct importance to the drainage engineer, although perhaps in a less degree than to the waterworks engineer. The average amount of rainfall which will percolate ordinary soil is about 23 per cent., and through chalk 38 per cent.; but during the winter months as much as 50 per cent. may so be lost, while in the summer, when vegetation and evaporation are in progress, it may fall to as low as 10 per cent. or even less. Again, the constancy of the rainfall has an important bearing: sudden and intermittent showers do not add much to the percolation. Snowstorms have also much to do with flooding of sewers, because while the snow lies on the ground no percolation takes place, and a thaw brings down enormous volumes of water. Failing any reliable records, however, of rainfall, the only course open to the engineer is to make calculations himself. This will necessitate the use of a rain gauge. There are various types on the market, some of which are self-registering and very satisfactory if they indicate the amount of rain falling during any portion of each hour every day, because the actual quantity is not of much importance, while the rate of fall and the time during which the rain fell are the determining factors. For instance, a fall of 2 in. may be registered on a certain day (an unusual fall in itself), yet the actual period during which rain fell may perhaps have been only one hour.

The hourly rates of rainfall as recorded in Belfast in the following table are typical of conditions in temperate climates.

Table IX.—Maximum Hourly Rates of Rainfall for Different Periods of Time, as recorded in Belfast during the Years 1904 to 1909.

Periods.	Rates of Rainfall per Hour.	Periods.	Rates of Rainfall per Hour.
5 minutes	2·712 inches	6 hours	0·212 inches
10 ,,	1·740 ,,	8 ,,	0·189 ,,
15 ,,	1·200 ,,	10 ,,	0·164 ,,
30 ,,	1·000 ,,	12 ,,	0·160 ,,
45 ,,	0·731 ,,	15 ,,	0·158 ,,
60 ,,	0·660 ,,	18 ,,	0·144 ,,
2 hours	0·363 ,,	20 ,,	0·138 ,,
3 ,,	0·282 ,,	24 .,	0·124 .,
4 ,,	0·240 ,,		

Extending over a period of six years, they are probably somewhat in excess of what should be allowed for, as it is scarcely wise to make provision for a fall which would occur only once in that period. It should be sufficient to take the average yearly maximum over the period of six years.

Dry-weather Flow.—Dry-weather flow is the amount of liquid contributed by the actual population. The water supply is usually the basis for its calculation, and the amount used per head per day should be capable of being easily ascertained. The ideal supply would be about 15 gallons per head per day, but, owing to leaks and misuse, this is nearly always exceeded. It may be even trebled, especially in manufacturing towns. Again, many firms have private water supplies, and waste waters all go to swelling the volumes in the sewers. It is indeed very difficult to make an accurate statement as to the quantity to be allowed for in this direction, but the engineer will usually be safe in taking 25 to 30 gallons per head per day, although Mr Wood, in his *Sanitary Engineering*, advises 18. Then there is the matter of *storm water*. Storm water is an important consideration, and if not adequately provided for it will bring about ultimate failure of any sewerage scheme sooner or later. The sewers may be too small to deal with the floods; on the other hand, they may be too large by reason of the engineer being over-anxious to provide for contingencies, with the result that in dry weather the sewers cease to have a self-cleansing velocity, and become stagnant and give rise to bad gas, often the precursor of epidemics. The matter of sewer ventilation will receive further consideration, but the following point demands attention here. Mr Fulton, the engineer of the Dundee main drainage, says:

"It is only when sewers are badly constructed as regards their form and water-run that putrid matters are retained in them to poison the surrounding atmosphere and bring disgrace on the very name of drainage." Again, if the sewers are not designed with a self-cleansing velocity, they must either be flushed or cleansed. The construction of flushing apparatus increases the capital outlay; cleansing runs away with revenue. The latter usually has to be done by hand, and may cost up to 10s. per cubic yard of deposit removed. Another way is to sweep the deposit along by flushing gates. It is unsatisfactory, because the water so ponded-up leaves a deposit behind it, and the value of the flush is soon lost by the velocity rapidly decreasing. The foul gases which will exist in a sewer necessitating such a procedure will also be driven forward and produce bad smells at the manhole gratings. Hence the vital necessity of all sewers having self-cleansing velocities, by being carefully proportioned to the area and population served, in accordance as to whether the combined, separate, or partially separate system is adopted.

Most towns at the present day are sewered on the combined system, viz. all the surface and other water as well as domestic sewage enters the sewers and goes away to the outfall or disposal works. Then there is the separate system, adopted in only a few cases, but advocated by many engineers. Here there must be two sets of sewers—one for the domestic sewage, which takes it away to the disposal works, and an entirely separate system for the storm waters.

That such a system does not work well is clearly evinced by the small amount of attention it has had. The author can find absolutely no recommendations for it: the expense is enormous; it is nearly always the case that the surface waters would be almost as foul as the sewage because of the filth necessarily abounding in the streets; especially in the first heavy rain after a long spell of dry weather must this be so, and what is to prevent ignorant people pouring their dirty water down the rain-water gullies instead of the special ones provided? One distinct advantage, of course, is the regular flow at the disposal works, and the decreased cost of pumping, if such has to be done. Theoretically it has great advantages, which are outweighed by the disadvantages of the sewers requiring good falls, with attendant increased excavation and "lift" in pumping (though the quantity is less); artificial flushing must be provided for, to say nothing of the increased cost of the extra amount of sewers. It is also generally recognised that the sewage from a separate system is more difficult to treat than that from a combined system. The partially separate system, in which road water goes into surface drains, and roof and yard water into sewers, has much to recommend it.

Storm Water.—Probably the most important calculation of all to the engineer designing a sewerage scheme is that of the allowance for storm water. It is the volume of rain-water which practically governs the size of the sewers. The dry-weather flow, which is usually equal to the water supply, is always more or less constant, and the maximum may be assumed at about twice the average. The storm-water flow is, however, very variable. It varies with the intensity and duration of the rainstorm, in conjunction with the extent and nature of the area drained.

"It has been found from experiments that in thickly populated towns with paved surfaces, from $\frac{2}{3}$ to $\frac{3}{4}$ of the total volume in heavy rainfalls finds its way into the sewers. Taking 4 in. per day as the minimum rate of rainfall of sufficient duration to reach the sewers, $\frac{2}{3}$, or 2·6 in. per day, may be taken as the extreme quantity that will ever require to be dealt with in such cases. In country towns and suburban districts, owing to the more absorbent surfaces upon which it falls, $\frac{1}{3}$ the maximum rainfall, or 1·3 in., will prove ample, while in rural districts from $\frac{1}{8}$ to $\frac{1}{4}$ in. per day would be as much as need be allowed for."[1]

In the first place, it is necessary to define the "drainage area," and then the maximum rainfall which is to be taken into account. Gauging existing sewers is often unsatisfactory, because perhaps only a percentage of the rainfall has entered those sewers. On a partially separate system the rain-water is restricted to roofs and back yards, which are considered as *impermeable.* In the combined system paved and macadam roads, gravel footpaths and gardens, are taken into account; in the last three named, moderate rainfalls seldom find their way into the sewers. Again, the slope of the ground is an important consideration, because areas which could otherwise be considered impervious will yield water to the sewers.

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[1] Mr E. B. Savage in *The Sewerage of a Small Town.*

It is important, then, when designing a new system of sewers, to restrict the drainage area as much as possible, utilising any existing streams, watercourses, and old sewers to take subsoil water and rainfall from *unbuilt-on* areas, which will leave actual paved areas only to be taken into account. No particular rates of rainfall can be taken in designing. Small sewers require the assumption of a very high rate, while the large sewers may work at a much lower rate. At the same time it must be borne in mind that a local authority is morally held responsible for flooding arising from the incapacity of the sewers to deal with such floods, unless they are *very* exceptional. The most convenient method of estimating the flow into each sewer is by considering each street independently, and calculating it per unit length, say 100 ft. at a time—that is, taking the area per 100-foot length. It will thus be seen that the storm waters in the sewer will increase by equal amounts per 100-foot length.

The volume flowing at any point in the sewer in question must be ascertained, bearing in mind that the velocity is increasing if the size of the sewer and the gradient remain constant. The time it will take for the storm water to travel from the head of the sewer to any point of it can then be calculated. Care must be taken, however, in selecting a point, to change the diameter of a sewer, attention being paid to bends, change of gradient, branch sewers, variation of proportion of paved surface, etc., and especially the concentration of storm waters from several branches, because one branch may bring down storm water which will pass off before another has any effect ; on the other hand, several branches may contribute large volumes simultaneously. The calculations for each branch should be worked out separately and tabulated, so that their effect may be calculated when designing the main sewer.

In designing a large system of sewerage, it is impossible to make provision for leading away all the storm water by means of the sewers. The sewers to do so would be of enormous size, and out of all reasonable proportion to the size necessary for the dry-weather flow. Storm overflows are therefore provided where suitable outlets can be obtained, but there are frequently large areas from which the storm water must be collected before a point for putting in a suitable overflow is reached.

When the volume of storm water is many times the volume of sewage, it is considered safe to have an overflow in the sewer, allowing the excess over a certain quantity to pass into a stream or river. The Ministry of Health generally requires that a storm overflow shall not come into operation until the combined flow of storm water and sewage is six times the average dry-weather flow. In large streams or rivers not utilised for water supply, sewage diluted to this extent will not do much harm, as the river or stream is swollen at the time the overflow takes place. On the other hand, it would be desirable to have a greater dilution where only a very small stream is available for the outlet. But this is not all. Subsoil water, surface water, and manufactures waste play a very important part in swelling up the volume, and the definition of the exact average quantity passing is a very hard question. Subsoil water must be kept out at all costs by properly designed sewers. Manufacturers' waste can usually be gauged at each works. Then, with the rainfall and the built-on area (assuming all other lands drain naturally into watercourses), an estimate of the average daily discharge may be made. For instance, the average rainfall may be 26 in. per year, but a very heavy storm may supply a downpour lasting half an hour at the rate of 72 in. per day. The only way to get satisfaction is to consult records, and find out the average hourly rainfall. Then, again, in some places the surface water may descend very rapidly into the sewers. On flat macadam roads, part of it may get lost or evaporate. However, on a paved street or an asphalt pavement nearly the whole of the rainfall will enter the sewers, especially in the case of a very sudden downpour. As an example take a built-on area of 80 acres$=\frac{1}{8}$ of a sq. mile, and allow for a crowded population of 10,000 people on the area and a water supply of 20 gallons per head per day.

$$\therefore \frac{20\times 10000\times 365}{6{\cdot}25}=12{,}000{,}000 \text{ cub. ft. per annum.}$$

Adding the rainfall, assume a fall of 24 in. per annum over the whole surface to be removed$=2\times 4840\times 9\times 80=$about $6\frac{1}{2}$ million cub. ft. of rainfall to be removed per annum$=18\frac{1}{2}$ million cub. ft. of sewage to be removed in a year. Now there are 525,600 minutes in a year, $\therefore \frac{18500000}{525600}=$about 35 cub. ft. per minute as the average dry-weather flow. This is merely an example; so many different circumstances crop up in special cases that no hard and fast rules can be laid down. Another thing which will help to determine the size of any particular sewer is the composition or strength of the sewage at the outfall. It must be analysed for albuminoid ammonia or oxygen absorbed, which on an average will be $1\frac{1}{2}$ grains of ammonia per gallon. The Ministry of Health's rules in reference to sewage going direct into streams demand that it shall be diluted before entering the said river down to 0·04 grain of albuminoid ammonia per gallon. Therefore it would be necessary to dilute the 35 cub. ft. to a flow of $35\times 37{\cdot}5=1312{\cdot}5$ cub. ft. per minute before permitting it to go into a river by means of a storm overflow. Providing for six times the average dry-weather flow, the 35 cub. ft.$\times 6=210$ cub. ft. of sewage to be taken and treated at the disposal works. Any quantity over and above this may go direct into the streams by the storm overflows. Now 210 cub. ft. per minute$=3{\cdot}5$ cub. ft. per second, and assuming a circular sewer to have a velocity in feet per second $=V=13{\cdot}725\sqrt{ds}$, d being the diameter of the pipe in inches and $s=$the fall.

Then with a fall of 1 in $240=\frac{1}{240}$, an 18-in. sewer would deliver 220 cub. ft. per minute when running half full. Therefore that would probably be the size of sewer selected for a population of 10,000 people on $\frac{1}{8}$ of a square mile. This size is that of the outfall after provision has been made for taking *all* the storm water over and above six times the DWF.

In order to calculate the amount of storm water per unit length of sewer as advised, the following very useful tables are of the utmost practical value. They were prepared by Mr P. H. M'Carthy, M.Inst.C.E., a Dublin engineer, for a paper read before the Institute of Civil Engineers in Ireland. The author is much indebted to him for his kind permission to publish them.

Again, as an alternative method, there is an empirical formula, based on the results of a civil engineer, Mr D. E. Lloyd Davies, to determine the quantity of rainfall likely to come into any sewer. It is impossible to take every contingency into account, and an approximation can only be aimed at, but if r=rainfall in inches during a certain period, t=the time of flow through the longest line of sewers in the district+the allowance for flow at entry, and P the percentage of impermeable area expressed in acres, then the discharge in cubic feet per minute is equal to

TABLE X.—GIVING THE FLOW OF VARIOUS AREAS ACCORDING TO THE RATES OF RAINFALL.

Rate of Rainfall.			Discharge in cub. ft. per min. from Areas in sq. ft. $=\frac{A}{L}\times 100$.										
Periods.	Ins. per hour.	Feet per min.	Sq. feet, 500.	Sq. feet, 1000.	Sq. feet, 2000.	Sq. feet, 3000.	Sq. feet, 4000.	Sq. feet, 6000.	Sq. feet, 8000.	Sq. feet, 10,000.	Sq. feet, 12,000.	Sq. feet, 15,000.	Sq. feet, 20,000.
Mins.													
5	2·712	0·00377	1·885	3·77	7·54	11·31	15·08	22·62	30·16	37·7	45·24	56·55	75·4
10	1·740	0·00241	1·21	2·41	4·82	7·23	9·64	14·46	19·28	24·10	28·92	36·15	48·20
15	1.200	0·00167	0·835	1·670	3·34	5·01	6·68	10·02	13·36	16·70	20·04	25·05	33·40
30	1·000	0·00138	0·690	1·38	2·76	4·14	5·52	8·28	11·04	13·80	16·56	20·70	27·60
45	0·731	0·00101	0·505	1·01	2·02	3·03	4·04	6·06	8·08	10·10	12·12	15·15	20·20
60	0·660	0·00091	0·455	0·91	1·82	2·73	3·64	5·46	7·28	9·10	10·92	13·65	18·20
Hrs.													
2	0·363	0·00051	0·255	0·51	1·02	1·53	2·04	3i06	4·08	5·10	6·12	7·65	10·20
4	0·240	0·00033	0·165	0·33	0·66	0·99	1·32	1·98	2·64	3·30	3·96	4·95	6·60

$$Q=\left(60{\cdot}5\times\frac{60}{t}\times r\right)\times P.$$

The considerations which Mr Lloyd Davies took into account in constructing this formula are—

(*a*) The total volume of storm water is considered as proportional to the maximum rate of flow.

(*b*) The storm-water discharge is assumed to be directly proportional to the percentage of impermeable area in any defined district.

(*c*) The maximum rate of flow is expected to occur when the average intensity of rainfall is greatest, considered over a period equal to the time of concentration.

(*d*) The discharge of storm water in underground channels is assumed to be proportional to the total rainfall during the time which the water occupies in travelling from the furthest boundary of the district to the point of observation. This is the time of concentration mentioned in (*c*).

At Rhyl, where the sewerage of the area is upon the combined system, and where there were no storm overflows, gaugings made by Mr Baldwin

TABLE XI.

Distance from Head of Sewer—Feet.	Quantity of Water contributed to Sewer per 100 feet length. Cubic feet per min.	Quantity of Water passing along Sewer. Cubic feet per min.	Diameter of Pipe.	Discharge flowing full. Cubic feet per min.	Velocity flowing full. Feet per min.	Ratio of Discharge to Discharge when full.	Ratio of Velocity to Velocity when full.	1 in 100. Velocity of Water in Sewer. Feet per min.	1 in 100. Time to Travel 100 feet. Minutes.	1 in 100. Time from Commencement of Storm. Minutes.
			Ins.							
0	..	0	9	102·42	231·83					
100	6·68	6·68	..	..	..	0·055	0·565	130	0·770	0·770
200	6·68	13·36	..	..	..	0·130	0·695	160	0·625	1·395
300	6·68	20·04	..	..	..	0·195	0·780	180	0·555	1·950
400	6·68	26·72	..	..	..	0·260	0·845	194	0·513	2·463
500	6·68	33·40	..	..	..	0 325	0·900	207	0·475	2·938
600	6·68	40·08	..	..	..	0·392	0·940	218	0·460	3·398
700	6·68	46·76	..	..	..	0·457	0·980	227	0·440	3·838
800	6·68	53·44	..	..	..	0·520	1·01	232	0·430	4·268
900	6·68	60·12	..	..	..	0·582	1·035	237	0·422	4·690
1000	6·68	66·80	..	..	..	0·650	1·065	246	0·407	5·097
1100	6·68	73·48	..	..	..	0·713	1·085	250	0·400	5·497
1200	6·68	80·16	..	..	..	0·780	1·105	255	0·390	5·887
1300	6·68	86·84	..	..	..	0·845	1·12	258	0·385	6·272
1400	6·68	93·52	..	..	..	0·910	1·13	260	0·385	6·657
1500	6·68	100·20	12	226·55	288·45	0·442	0·97	287	0·350	7·007
1600	6·68	106·88	..	..	..	0·472	0·982	288	0·347	7·354
1700	6·68	113·56	..	..	..	0·502	1·000	288	0·347	7·701
1800	6·68	120·24	..	..	..	0·535	1·015	300	0·333	8·034
1900	6·68	126·92	..	..	..	0·560	1·03	306	0·326	8·360
2000	6·68	133·60	..	..	..	0·590	0·04	310	0·322	8·682
2100	6·68	140·28	..	..	..	0·620	1·05	313	0·318	9·000
2200	6·68	146·96	..	..	..	0·650	1·065	317	0·315	9·315
2300	6·68	153·64	..	..	..	0·680	1·075	320	0·313	9·628
2400	6·68	160·32	..	..	..	0·710	1·080	322	0·311	9·939
2500	6·68	167·00	..	..	..	0·740	1·092	325	0·308	10·247
2600	6·68	173·68	..	..	..	0·770	1·100	327	0·305	10·552
2700	6·68	180·36	..	..	..	0·800	1·110	330	0·303	10·855
2800	6·68	187·04	..	..	..	0·830	1·117	332	0·302	11·157
2900	6·68	193·72	..	..	..	0·855	1·120	334	0·300	11·457
3000	6·68	200·40	..	..	..	0·890	1·127	336	0·297	11·754
3100	6·68	207·08	..	..	..	0·920	1·132	338	0·295	12·049
3200	6·68	213·76	..	..	..	0·950	1·135	341	0·293	12·342
3300	6·68	220·44	15	417·88	340·52	0·527	1·01	344	0·291	12·633

Latham for two entire years (1900–1901) gave the figures shown in Table XIV., p. 54 (Report[1] by Mr Baldwin Latham to the Commission, June 29, 1903, pp. 3 and 17).

In his report Mr Baldwin Latham gives the figures (Table XV., p. 54) for Deal, which was also sewered on the combined system and had no storm overflows.

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[1] Appendix V.—Royal Commission on Sewage Disposal.

Table XII.

Distance from Head of Sewer—Feet.	Quantity of Water contributed to Sewer per 100 feet length. Cubic feet per min.	Quantity of Water passing along Sewer. Cubic feet per min.	Diameter of Pipe.	Discharge flowing full. Cubic feet per min.	Velocity flowing full. Feet per min.	Ratio of Discharge to Discharge when full.	Ratio of Velocity to Velocity when full.	1 in 200.		
								Velocity of Water in Sewer. Feet per min.	Time to Travel 100 feet. Minutes.	Time from Commencement of Storm. Minutes.
			Ins.							
0	..	0	9	72·27	163·58					
100	6·68	6·68	..	..	..	0·094	0·62	102	0·980	0·980
200	6·68	13·36	..	..	..	0·184	0·76	125	0·800	1·780
300	6·68	20·04	..	..	..	0·277	0·855	141	0·710	2·490
400	6·68	26·72	..	..	..	0·368	0·925	150	0·670	3·160
500	6·68	33·40	..	..	..	0·460	0·980	161	0·620	3·780
600	6·68	40·08	..	..	..	0·550	1·03	169	0·590	4·370
700	6·68	46·76	..	..	..	0·650	1·065	175	0·572	4·942
800	6·68	53·44	..	..	..	0·740	1·092	179	0·555	5·497
900	6·68	60·12	..	..	..	0·840	1·118	183	0·545	6·042
1000	6·68	66·80	..	..	..	0·920	1·132	186	0·535	6·577
1100	6·68	73·48	12	159·89	203·58	0·460	0·98	200	0·500	7·077
1200	6·68	80·16	..	..	..	0·500	1·000	204	0·490	7·567
1300	6·68	86·84	..	..	..	0·545	1·02	207	0·485	8·052
1400	6·68	93·52	..	..	..	0·585	1·038	212	0·473	8·525
1500	6·68	100·20	..	..	..	0·630	1·055	217	0·462	8·987
1600	6·68	106·88	..	..	..	0·670	1·070	218	0·460	9·447
1700	6·68	113·56	..	..	..	0·705	1·080	220	0·455	9·902
1800	6·68	120·24	..	..	..	0·755	1·097	224	0·446	10·348
1900	6·68	126·92	..	..	..	0·795	1·107	226	0·442	10·790
2000	6·68	133·60	..	..	..	0·830	1·116	228	0·436	11·226
2100	6·68	140·28	..	..	..	0·88	1·126	229	0·435	11·661
2200	6·68	146·96	..	..	..	0·92	1·132	231	0·434	12·095
2300	6·68	153·64	..	..	..	0·955	1·135	232	0·433	12·528
2400	6·68	160·32	15	294·98	240·37	0·543	1·02	248	0·400	12·928
2500	6·68	167·00	..	..	..	0·565	1·03	252	0·396	13·324
2600	6·68	173·68	..	..	..	0·590	1·036	253	0·395	13·719
2700	6·68	180·36	..	..	..	0·610	1·046	255	0·392	14·111
2800	6·68	187·04	..	..	..	0·635	1·058	258	0·387	14·498
2900	6·68	193·72	..	..	..	0·655	1·065	260	0·385	14·883
3000	6·68	200·40	..	..	..	0·680	1·075	262	0·383	15·266
3100	6·68	207·08	..	..	..	0·705	1·082	264	0·380	15·646
3200	6·68	213·76	..	..	..	0·725	1·086	266	0·376	16·022
3300	6·68	220·44	..	..	..	0·748	1·095	268	0·373	16·359

Calculations having Special Reference to the Sewerage of Seaboard Towns.

As there are many points affecting the design of a sewerage system for a seaboard town which materially differ from other towns, the special points will be discussed here, assuming that the sewage is finally discharged into tidal waters. The first consideration is that of tides, and the effect of foul waters discharged into tidal waters.

Some of the best evidence on this score is set forth in the First Report of the Royal Commission, the Metropolitan Sewage Discharge, 1885, in which

TABLE XIII.

Distance from Head of Sewer—Feet.	Quantity of Water contributed to Sewer per 100 feet length. Cubic feet per min.	Quantity of Water passing along Sewer. Cubic feet per min.	Diameter of Pipe.	Ratio of Discharge to Discharge when full.	Ratio of Velocity to Velocity when full.	1 in 300.		
						Velocity of Water in Sewer. Feet per min.	Time to Travel 100 feet. Minutes.	Time from Commencement of Storm. Minutes.
			Ins.					
0	..	0	9					
100	6·68	6·68	..	0·131	0·69	79	1·260	1·260
200	6·68	13·36	..	0·262	0·845	97	1·030	2·290
300	6·68	20·04	..	0·402	0·945	109	0·910	3·200
400	6·68	26·72	..	0·525	1·015	117	0·850	4·050
500	6·68	33·40	..	0·660	1·065	123	0·810	4·860
600	6·68	40·08	..	0·780	1·105	127	0·790	5·650
700	6·68	46·76	..	0·92	1·132	130	0·770	6·420
800	6·68	53·44	12	0·475	0·985	141	0·710	7·130
900	6·68	60·12	..	0·535	1·016	145	0·685	7·815
1000	6·68	66·80	..	0·595	1·040	149	0·670	8·485
1100	6·68	73·48	..	0·655	1·065	153	0·650	9·135
1200	6·68	80·16	..	0·715	1·085	156	0·640	9·775
1300	6·68	86·84	..	0·775	1·105	159	0·630	10·405
1400	6·68	93·52	..	0·835	1·117	160	0·625	11·030
1500	6·68	100·20	..	0·895	1·128	161	0·615	11·645
1600	6·68	106·88	..	0·955	1·135	163	0·610	12·225
1700	6·68	113·56	15	0·546	1·02	173	0·570	12·825
1800	6·68	120·24	..	0·580	1·035	175	0·570	13·395
1900	6·68	126·92	..	0·610	1·046	177	0·565	13·960
2000	6·68	133·60	..	0·645	1·060	179	0·560	14·520
2100	6·68	140·28	..	0·675	1·072	181	0·550	15·070
2200	6·68	146·96	..	0·700	1·080	183	0·545	15·615
2300	6·68	153·64	..	0·740	1·092	184	0·540	16·155
2400	6·68	160·32	..	0·770	1·101	186	0·540	16·695
2500	6·68	167·00	..	0·80	1·111	188	0·530	17·225
2600	6·68	173·68	..	0·835	1·117	189	0·530	17·755
2700	6·68	180·36	..	0·870	1·123	190	0·525	18·280
2800	6·68	187·04	..	0·900	1·129	191	0·520	18·320
2900	6·68	193·72	..	0·93	1·133	191	0·520	19·335
3000	6·68	200·40	..	0·965	1·136	192	0·520	19·825
3100	6·68	207·08	18	0·605	1·045	202	0·495	20·235
3200	6·68	213·76	..	0·625	1·055	204	0·490	20·725
3300	6·68	220·44	..	0·642	1·060	205	0·487	21·312

it is stated that eleven and a half millions of cubic feet of concentrated sewage then entered the river Thames during three hours every tide. The main outfalls are at Barking and Crossness, on the north and south sides of the river respectively, the sewage being formerly let out on the ebb tides and stored in tanks at other times. The solid matter in the sewage decomposed, and the river water dissolved the gas given off, which escaped when agitated by the passage of passing steamers.

The water was stated to be so foul as to be unfit for washing ships' decks. Lower down the river, however, the natural oxidation caused the nuisance

TABLE XIV.

Rainfall.	Number of Days on which 0·01 inch or more Rain fell.	Total Flow in Sewers.	Dry-weather Sewage Flow, including Subsoil Water.	Water Supply.	Rainfall flowing off (*i.e.* increase in Flow due to Rain).	Rainfall and Subsoil Water.
Inches.		Gallons.	Gallons.	Gallons.	Gallons.	Gallons.
1900 26·52	168	165,683,520	123,281,534	91,438,652	42,401,986	74,244,868
1901 20·46	139	159,161,870	121,825,485	97,385,727	37,336,385	61,776,143

TABLE XV.

September 1901 to February 1903 inclusive.

Rainfall.	Number of Days on which 0·01 inch or more Rain fell.	Total Flow in Sewers.	Dry-weather Flow.	Rainfall flowing off.	Water Supply to District.
Inches.		Gallons.	Gallons.	Gallons.	Gallons.
33·525	250	183,996,063	152,883,153	31,112,910	136,059,220

to be somewhat abated, and below Greenhithe it was inappreciable. The same thing took place in the Liffey in Dublin until a few years ago, due to the sewage going direct and unpurified into the Liffey. The writer has known the smells on the quays to be not only disagreeable, but actually sickening and nauseating. It is, however, much to the credit of the city engineers that the new main drainage works have vastly improved this river, so much so that fish have been reported at Custom House Quay. This improvement is all the more manifested by the fact that during a temporary stoppage of the works in 1909, by silting up of the new outfall, the river in the space of a few days gave rise to complaints and discussion in the papers from all parties.

Another aspect of the question is the silting up of the channel, and consequent hindrance to navigation: the Mersey, Clyde, and Avon have suffered from this cause, while it has been shown in one instance that, inland, the raising of the river-bed has caused flooding of the surrounding country, evils which may be even increased by the alkaline constituents of the sewage decomposing and depositing the calcareous constituents of the water.

In tidal waters the effects of pollution are not confined to the channel below the outfall. The same evils exist above it, it having been proved in the Thames, by means of floats, that considerable oscillation of the sewage takes place due to the tides, especially during the change from spring tides to neap tides. The continual flow of fresh water, however, tends to somewhat mitigate this mixing action, which will also take place due to the difference in the specific gravities of the liquids and the continual outward flow. It has been pointed out that the purifying effect on sewage passing down a river channel is due mostly to oxidation. This, however, is not all. There always exist animals and plants of a low type which feed upon the sewage, such as water-fleas, minute algæ, and bacteria, the last mentioned being found more especially in polluted backwaters, their purifying effect consisting in oxidising the principal constituents of the sewage to carbon dioxide and water.

Summing up :

The principal evils which arise out of letting crude sewage into tidal estuaries are—(*a*) The considerable length of time which it takes large volumes to actually reach the sea, especially in dry weather, due to oscillation.

(*b*) The various salts contained in sea-water cause considerable precipitation of organic matter, while at the same time they retard oxidation and purification, and hence in tidal estuaries there is a noticeable quantity of brown slimy mud deposit.

Hence the vital necessity of effectually and permanently disposing of sewage which is turned into tidal waters, and the efficiency of the process is primarily dependent upon the nature of the currents, which must be fully understood from the outset. Currents are caused by the natural rise and fall of the tide, which in turn primarily depends on the actions of the moon and sun conjointly. A full description of the phenomena would be quite out of place in an engineering text-book, and the reader is referred to standard works on physical geography, etc. ; suffice to say[1] that the height from high to low water of spring tides is approximately double that of neap tides, while the maximum height to which spring tides rise is about 33 per cent. more than neaps, taking mean low water of spring tides as the datum. Extraordinarily high tides may be expected when the moon is new or full, and in her position nearest to the earth, at the same time as her declination is near the Equator, and they will be still further augmented if a strong gale has been blowing for some time in the same direction as the flood tide in the open sea, and then changes when the tide starts to rise, so as to blow straight on to the shore. The pressure of the air also affects the height of tides, in so far as an increase will tend to depress the water in one place, and a reduction of pressure will facilitate its rising elsewhere, so that if there is a steep gradient in the barometrical pressure falling in the same direction as the flood tide, the tides will be higher. Exceptionally high tides do not generally occur on our shores more frequently than perhaps once in ten years, although there may be many extra high ones during this period of ten years from on-shore gales. Where tides approach a place from different directions, there may be an interval between the times of arrival, which results in there being two periods of high and low water, as at Southampton, where the tides approach from each side of the Isle of Wight. Much valuable information on this subject is contained in the following books, among others: *The Tides*, by G. H. Darwin, 1886; Baird's *Manual of Tidal Observations*, 1886; and *Tides and Waves*, by W. H. Wheeler, 1906; together with the articles in the *Encyclopædia Britannica* and *Chambers' Encyclopædia*.

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[1] Adams, H. C., *The Sewerage of Sea Coast Towns.*

The level of high and low water of the ordinary spring and neap tides is ascertained together with the rate of rise and fall of the various tides, and the special observations in the case of the equinoctial tides. An automatic tide-recording instrument should be used (of which there are many on the market) giving a 24-hour continuous diagram. The data so obtained will be of the utmost value, because general deductions obtained during a limited period only are usually very unreliable. The gauges must be set in deep water, under the shelter of a pier or quay-wall, so as to be away from the disturbing influences of waves. The float must be in such a position as never to be dry at low water: special wells are sometimes built for them. Observations of the kind should be carried out in the spring, viz. March to June inclusive, and continuous tidal records plotted from the data so obtained. The engineer must also make quite sure to what standard the high-tide levels are referred to; it is also essential that such levels be referred to the Ordnance datum.

The levels adopted for tidework vary in different ports.[1] Trinity high-water mark is the datum adopted for the port of London by the Thames Conservancy; it is the level of the lower edge of a stone fixed in the face of the river wall upon the east side of the Hermitage entrance of the London Docks, and is 12·48 ft. above Ordnance datum. The Liverpool tide tables give the heights above the Old Dock Sill, which is now non-existent, but the level of it has been carefully preserved near the same position, on a stone built into the western wall of the Canning Half-Tide Dock. This level is 4·67 ft. below Ordnance datum. At Bristol the levels are referred

TABLE XVI.—RATE OF FALL OF TIDES.[1]

State of Tides.	Equinoctial Tides.	Ordinary Spring Tides.	Ordinary Neap Tides.	Lowest Neap Tides.
High Water.				
½ hour after	0·44	0·40	0·22	0·19
1 " "	0·96	0·80	0·40	0·31
1½ " "	1·30	1·14	0·68	0·53
2 " "	1·85	1·56	0·72	0·59
2½ " "	1·91	1·64	0·84	0·68
3 " "	1·94	1·66	0·86	0·70
3½ " "	1·94	1·66	0·86	0·70
4 " "	1·91	1·64	0·84	0·68
4½ " "	1·35	1·16	0·59	0·48
5 " "	1·27	1·09	0·57	0·46
5½ " "	1·06	0·91	0·47	0·38
6 " "	1·04	0·89	0·46	0·37
6½ " "	0·53	0·45	0·24	0·18
Totals	17 ft. 6 in.	15 ft.	7 ft. 9 in.	6 ft. 3 in.

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[1] Adams, H. C., *The Sewerage of Sea Coast Towns.*

to the Old Cumberland Basin (O.C.B.), which is an imaginary line 7·58 ft. below Ordnance datum. Again, it must not be supposed that the rise and fall of a tide is by any means constant over the periods of rise and fall; that is to say, at high and low tide there are periods of practically no fluctuation in the water-level and varying to a maximum rate at half-tide level. Some results are tabulated in Table XVI.

CHAPTER IV.

PRACTICAL CONSTRUCTION: TRENCHES AND TUNNELS.

In considering the methods of constructing sewers, actual forms of sewer, which will receive attention in the following chapter, are not referred to, but rather the work of preparing the trenches and tunnels and other works preparatory to the sewers being laid therein. Much of this work is of a very difficult and treacherous nature, and its proper carrying out demands much skill, ingenuity, and experience on the part of the engineer, who will have to adapt his methods to the particular works in question. In fact, so widely divergent are the ways and means of carrying out actual engineering works in a practical manner, that it is useless to attempt the question on paper. Experience alone is a safe guide; and it is the intention to discuss here the principles upon which such works should be carried out, leaving the reader to decide how he will put these principles into practice. The opportunity is also taken of impressing upon the young engineer the advisability of watching similar works in progress whenever the opportunity arises, and taking copious notes and sketches of the methods there employed. The view of contractors and foremen upon special points should always be asked for, their opinions noted and compared with the principles enumerated, to verify their feasibility.

It may be taken for granted, too, that when a contractor adopts a certain mode of construction with satisfaction to himself, that it is efficient, cheap, and to be recommended.

Having drawn up plans, etc., taken levels, plotted the sections of a sewerage scheme (as advised in Chapter I.), found the sizes of the sewers, and made other hydraulic calculations, as set out in Chapters II. and III.; having also settled the position of all storm overflows, etc., and all the details possible for the time being, which should include borings to ascertain the nature of the subsoil, the engineer's business is to start the works. One says "details for the time being," because no matter how careful and experienced the designer of drainage works may be, there will always occur to him improvements, omissions, deviations, and additions to the original plans as the work proceeds. A section of sewer having been set out on the ground and the width of the trench indicated, the ground is opened up. The top width of the trench varies, of course, with the depth and nature of the ground.

Setting Out.—The foreman can direct his men to go down to within a few inches of the depth found on the sections by the aid of a 2-foot rule, and then the engineer or clerk of works comes on the works to set out the exact depths. Pegs will probably have been driven into the ground at surface-level at various points of the proposed work. They will be referred to the Ordnance datum, and have the heights painted on another peg driven slantwise, and also referred to on the plans. Various fixed points may also have their levels ascertained, and may serve the same purpose. Referring to the section and the heights of these pegs, and assuming all the new works have been marked thereon in red ink, the setting out of a trench, say (for example) 420 yards long, and having a gradient of 1 in 200, proceeds as follows.

If at the beginning of such a work the height above datum at surface is 27·04 ft., and the depth of trench at the point was calculated at 7 ft. 6 in. =7·5 ft., then 27·04−7·5=19·54, the height above Ordnance datum of the bottom of the trench at that point is 19·54 ft.

Now assuming a short distance away (say 120 ft.) a peg at 23·24 ft. above O.D., with these figures painted thereon (which it is advisable always to do on such pegs as are frequently referred to); the level is set up about midway between that peg and the one to be set. Having directed the foreman to drive in his peg lightly to what he considers a near approximation to the correct level, someone holds a staff on the set peg and the reading is booked. Assume it to be 4·51. Now it is desired to set the new peg to 19·54, and 23·24−19·54=3·70 ft. below the set peg. If the last reading (the back sight) was 4·51, a fall in the ground means a rise in the staff. Adding 3·70 to 4·51:

$$\begin{array}{r} 4{\cdot}51 \\ 3{\cdot}70 \\ \hline 8{\cdot}21 \end{array}$$

The staff is now held on the new peg, which is driven down or raised till the staff reading is exactly 8·21. The peg is then set. With 420 yards of trench at a gradient of 1 to 200: assume that it can be seen from end to end, although in practice this will not always be the case. Now $\frac{420}{200}\times 3=2{\cdot}10\times 3$, that is a rise or fall (say rise, because it is wise to start a drain at the lowest point wherever possible) of 6·30 ft. in 420 yards. Therefore at the other end a peg must be set whose height above Ordnance datum is 19·54+6·30=25·84 ft. above O.D. Resetting the level between the two points and reading the staff when held on the point just set, assume it to be 10·30. The peg must be set 6·30 above this, and must therefore be adjusted till the staff reading is 4·00. The two ends of the trench are now set at the correct levels—although this reverse process of levelling is somewhat confusing at times to the young engineer—and the rest may be set out by the engineer or foreman in charge, by means of what are termed "boning rods."

These are illustrated in fig. 42. Their use is simply to give a straight line in a vertical plane between two fixed points, whether up or down hill or on the level; in other words, they enable a uniform gradient to be kept between the two fixed points. A boning rod is like a rough tee-square used with the blade upright and the crosspiece horizontal. Not less than three of identical height are used together, as follows. Pegs having been driven so as to give the level at the two extremities of the section (which may be part of a much longer line), the point of a boning rod is held on each of the pegs, while the third boning rod is held at any intermediate point or points where the level is required. The surveyor or foreman sights through over the crossbar of the boning rod on one of the pegs to that on the other peg, and the man at the intermediate boning rod raises or lowers it, by signal from the surveyor, until the top sights through with the end rods, as shown in the accompanying diagram. The point of the intermediate rod may have to be lowered, the earth being kicked away and flattened, or may have to be raised by putting a brick or two underneath, but small wooden pegs are easily fixed to the required level and are more distinctive. When giving an example of setting out levels, two pegs were put in 420 yards apart. This, in practice, is too long a base over which to use the boning rods to ensure accuracy, 100 to 200 ft. being quite far enough apart for this purpose.

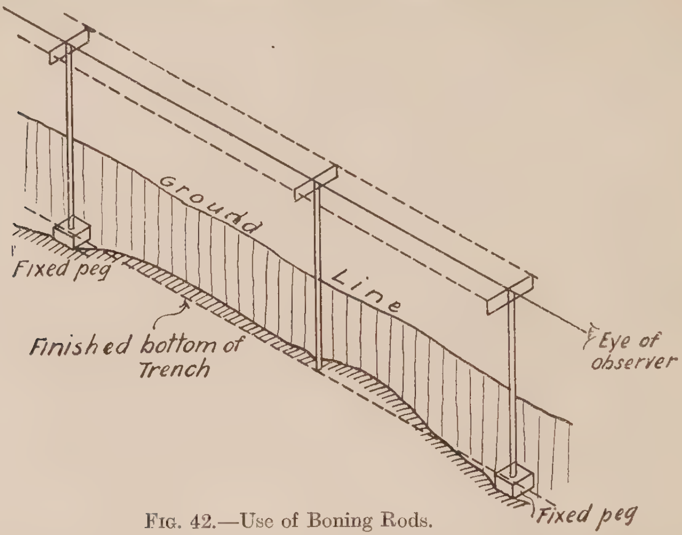


FIG. 42.—Use of Boning Rods.

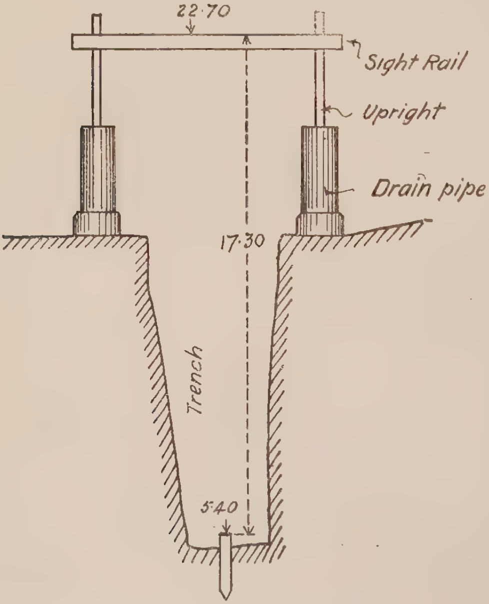


FIG. 43.—Use of Sight Rail.

Sight rails are also often used in preference to boning rods to replace the two end ones. They are set up in two pipes, as in fig. 43. The engineer very carefully has the tops of these two rails set to the correct level according to gradient. Immediately below them are set pegs. Then a boning rod of a length=distance from top of rail to top of peg is provided. The procedure is then the same as before, simply sighting over the rails instead of two boning rods.

Shoring.—In laying sewers in trenches, except in very compact earth and hard rock, and where the trench is very shallow, it is always most essential to prevent the sides (which are generally vertical, as opposed to larger cuttings for roads and railways) from falling in and injuring the works and workmen. This is done by what is termed timbering. It must be carefully done by experienced workmen. Rough timber is used, generally of the spruce variety, but pitch pine and red deal are sometimes used for the struts and walings. The timber used is spoken of in three ways, according to its purpose.

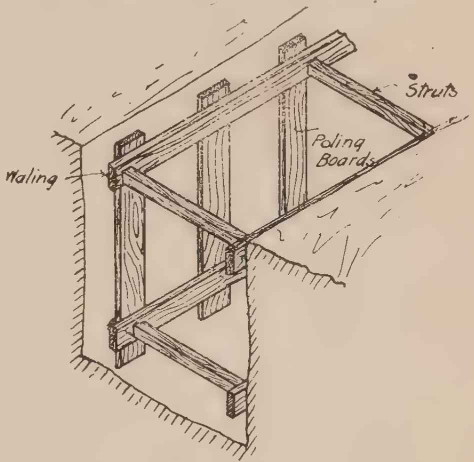
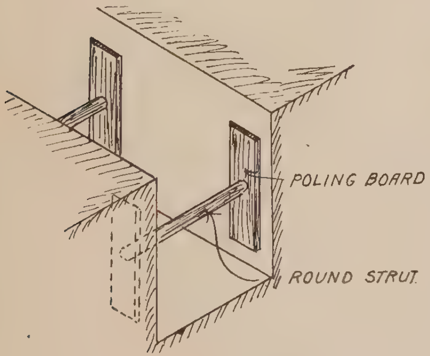
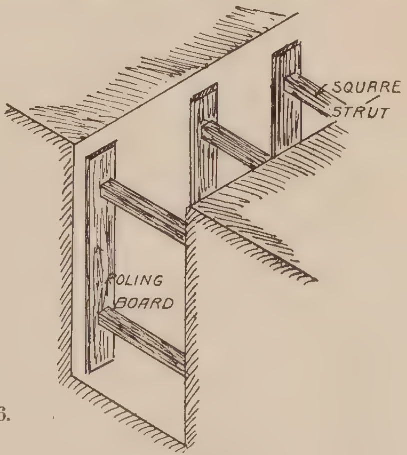


Fig. 44.

In fig. 44 the short boards placed vertically are called *poling boards*. These are held in place by horizontal boards of stouter section, called *walings* or *wales*, while these in turn are wedged hard against the sides of the trench by *struts*. Walings are not always employed; the struts may bear directly on the poling boards if deemed advisable, as shown in figs. 45 and 46. Fig. 47 shows the boards quite close for use in loose earth.





Figs. 45 and 46.

Deep trenches have to be run in stages, because the limit of height to which a man can conveniently shift earth out of a trench is about 7 ft. when the trench is deep.

Then on this stage, which is supported on the struts, another man stands and shifts out the earth from the man below to the man on the stage above. These struts are of course always made slightly longer than required, so as to form wedges and keep the walings quite tight. Where the soil is particularly treacherous, runners may be necessary. They are close poling boards (fig. 48), and are driven down by a mallet as the excavation proceeds behind the walings. By this process none of the soil is exposed. When these have been driven, another set is driven inside them; this, of course, tends to reduce the trench width, in which case a suitable allowance is always made. When the pipe or culvert has been laid, the filling is carefully proceeded with and the timbering removed. If this is carefully done it may often be used for other purposes.

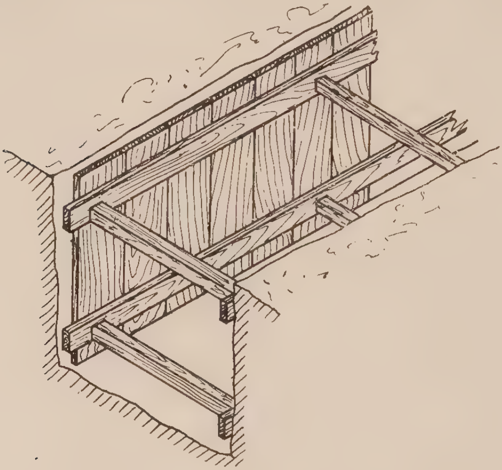


Fig. 47.—Close Poling Boards.

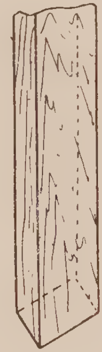


Fig. 48.—Runner.

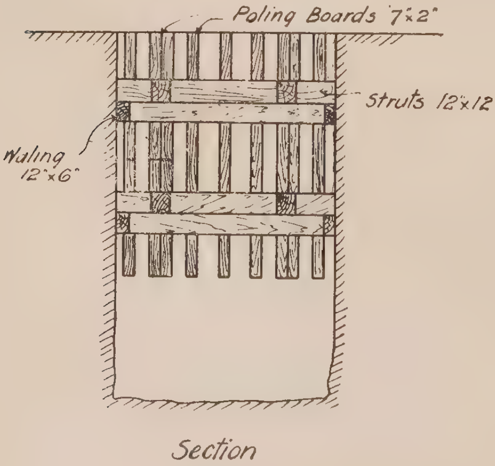


Fig. 49.

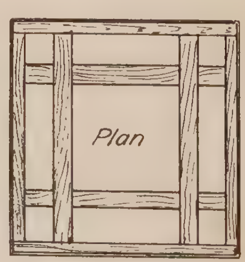


Fig. 50.

In the case of very bad ground it may sometimes be left in for security, at the engineer's discretion. The timbering for a large hole is shown in figs. 49 and 50, such as would occur in excavating for a manhole or deep tank, etc.

Fig. 51 shows a form of timbering on somewhat different principles to these set forth. Being fairly deep and in bad ground, there are two sets of runners (or what is technically known as doing the trench with two *settings*).

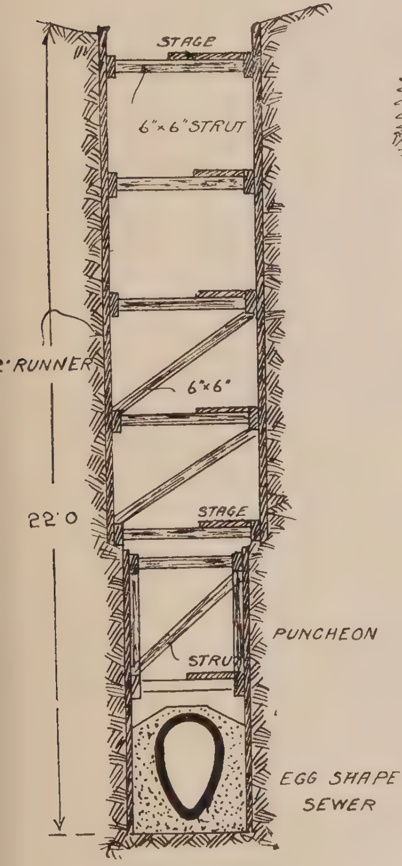


FIG. 51.

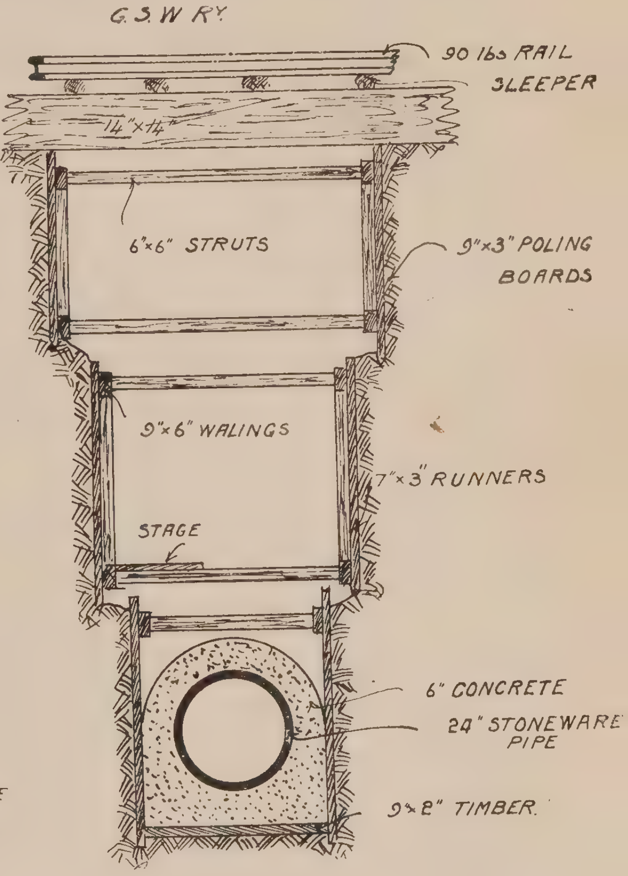


FIG. 52.

In this case also there are two raking struts and vertical props. The duty of these props is to support the walings. They are known as *puncheons*, and in some districts as *soldiers*. The use of the raking strut in this particular case is to resist abnormal pressure on one side of the trench, which might be caused by the ground being very wet and liable to slide, such as mud. Another case which the reader may have to contend with is that of a main line of railway crossing over the proposed trench, not as shown in Plate II., where it was proposed to tunnel, but as a level-crossing. In a case of this sort the railway (or tramway) company's engineer should be consulted, who will give information regarding the weight of the heaviest locomotives. A main line goods locomotive in Britain may weigh as much as 150 tons in working order. An example of work carried out by the writer in County Dublin for a 24-in. sewer is shown in figs. 52 and 53. The traffic was not abnormally heavy. The heaviest locomotive on the railway is 100 tons. The span was 8 ft. Taking the load, as suddenly applied, equal to 200 tons, viz. 100 tons on each stringer, and using a pitch pine timber 14×14, its safe load is

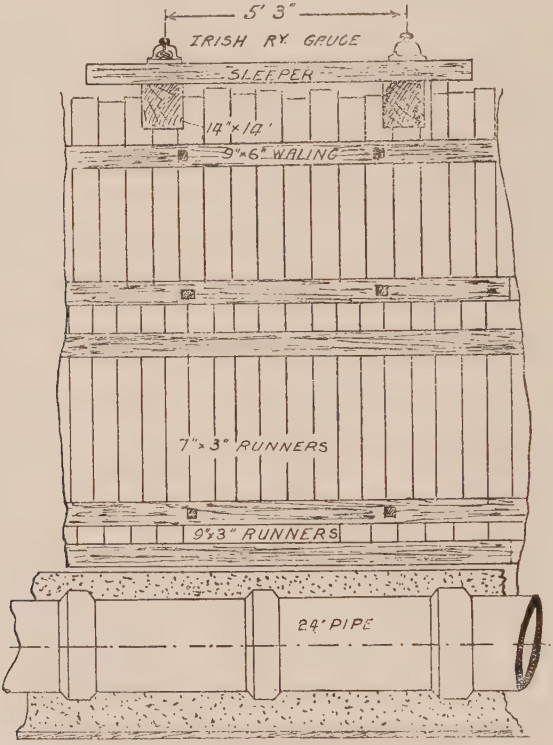


FIG. 53.

$$W=\frac{2Cbd^2}{L}=\frac{2\times3\times14\times14\times14}{8}$$

=nearly 103 tons. The use of short top poling boards is advisable in a case of this sort, because, by having them so, the railway traffic will suffer less interference by their standing up above rail-level when being fixed in position.

Steel Piling.—An invention which now finds favour amongst engineers in this direction is steel piling. It has been much used in America, and its life is at least three times as long as timber piling, so the cost of driving is proportionally less. It is especially useful in wet and waterlogged ground. The simplest form consists of steel plates having curved ends, as in fig. 54, about 12 in. wide and $\frac{3}{8}$ in. thick, and weighing about 35 lb. per square foot. In fig. 55 is shown special rolled plates with joints on the ball and socket principle; this is useful for curved portions of the work. The plates are usually 12 in. wide and $\frac{3}{8}$ in. thick, and weigh not more than the previous example. Another arrangement is that shown in figs. 56 and 57, which is formed of ordinary steel channels with zed bars riveted on to form a locking arrangement. They are made up in 60-ft. lengths, and may even then be joined by fish-plates. These forms would not be of service if they had to sustain concrete, because the inside faces are not flush. In this case a special form has been introduced, as shown in figs. 58 and 59, the rivets in each case being countersunk on the inside. Both the examples weigh less than the previous ones. Fig. 60 shows a very heavy form. The thickness of steel sheet piling being so small when compared with timber that it may be considered as always having a cutting edge, which allows of it being driven down slightly in advance of the excavation, but the piles have chisel or V-pointed edges if desired, at a slightly higher cost. Another advantage of the system is, that struts are not usually required, allowing more facilities for workmen and the lowering of large pipes. If strutting is required it takes the form of a modification of the mechanical engineer's bottle jack, having ball and socket joints at each end. In large contracts, where a mechanical excavator is introduced, the timber struts used in ordinary work would make it very inconvenient, if not an impossibility.

The "Universal" joist steel sheet piling is composed of 15 in. by 5 in. British standard joists and a standard interlocking member made from a $6\frac{3}{16}$-in. by 4-in. joist turned over by a special process. The interlocking member or clutch is run on to the flange of the joist before driving, so that each pile consists of one joist and one clutch. This form of interlock is suitable for all British standard joists, so that any desired width of joist can be used to make up an exact distance.

The method of driving is to commence with a plain joist, great care being taken to see that it is perfectly plumb all ways, then continue with one clutch and joist together, driving the clutch over the flange of the joist last driven; this prevents the interlock filling with soil. A steel driving cap is used to protect the heads of the piles where it is desired to use the piling repeatedly, but in some cases for permanent work, where the driving is very free, this may be dispensed with. Owing to the great accuracy with which the piling is made, the clearance is sufficient to enable the piles to drive freely, and yet small enough to prevent the water passing through. Each clutch has four points of contact, so that it is very difficult for the water to pass through, owing to its having to take such a long journey round the clutch; but should there be a small space, it gets filled up in the course of a few hours from the dirt in the water, or where there is no dirt, from the road sweepings which may be thrown in.

For cofferdam work it is usual to set up the piling in position and work round it with the piling plant, so as to get all the piles down together and ensure closing. This piling may be used for all classes of cofferdams, retaining-walls, mine shafts, sea defence works—in fact, in all cases where it is necessary to retain soil or water, or the two combined. It has greater strength than any other piling on the market, and consequently can be driven to great depths.

Running sand, which is always a difficult problem with timber piling, is

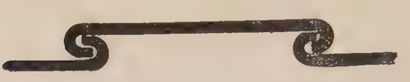


Fig. 54.

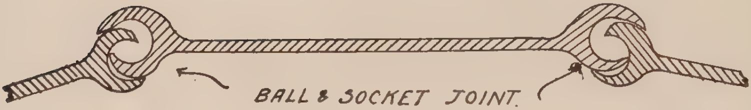
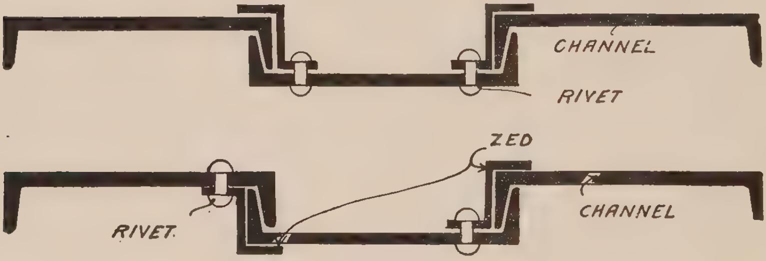


Fig. 55.



Figs. 56 and 57.

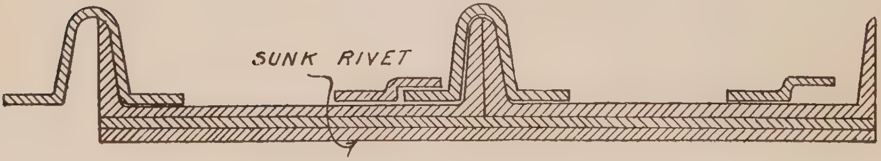


Fig. 58.

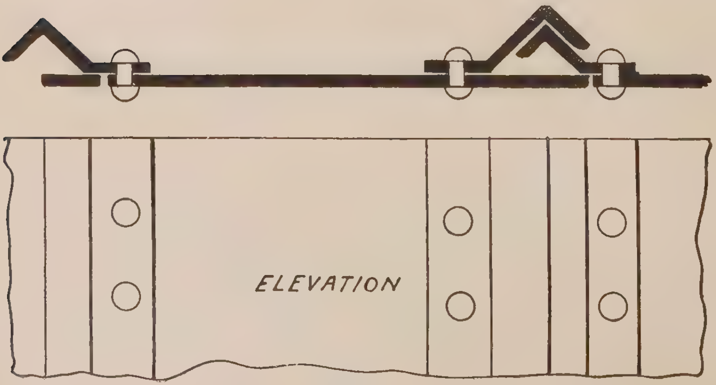


Fig. 59.

a simple proposition with Universal joist piling, as the displacement is so small in comparison that it can be easily and rapidly driven, where a timber pile refuses. The same applies to all compact soils.

Tunnelling.—It is now generally recognised that for sewers over 30 ft. deep, trenching, as described, becomes more expensive than tunnelling, and attention is now directed to this construction. It requires very carefully executing on the part of the engineer. The centre line has first to be ascertained and set out above ground. The method is fully described in the author's *Civil Engineering Practice*. The engineer proceeds to set out on the ground (by accurately chaining from known points) the exact position of manholes, storm overflows, flush tanks, etc. The manholes usually become the shafts for tunnelling, and are consequently, for economic reasons, further apart than in ordinary cut-and-cover work. The shafts are generally sunk at each end of the tunnel. Their use is, of course, for—

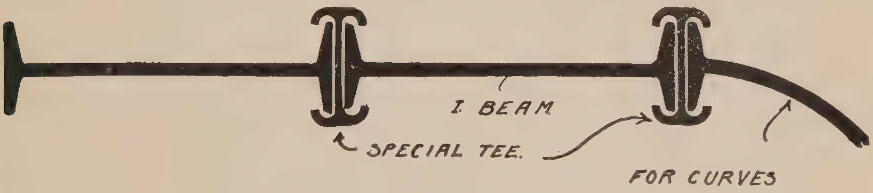


Fig. 60.

(1) Means of exit and entry for men and materials.
(2) Ventilation.
(3) Setting out the centre line below ground, and transferring the surface-levels to the workings.

In shallow work the sinking of the shaft is only a modification of the procedure in figs. 49 and 50, but it is often more complicated if great depths are necessary. It is not usual, however, for such depths to be encountered in sewerage work as in railway work; but, for the benefit of the reader, the system of sinking deep shafts is briefly described. The shafts must be sunk to the full diameter of the outside of the intended brickwork if the earth is considered safe. A timber curb is then laid on the bottom of the excavation, having a clear diameter internally the same as the proposed brickwork, and externally equal to the internal diameter and twice the thickness of the brickwork. This curb is usually made of oak segments, the joints being half lapped with plates on each side, and four bolts passed through all. The sinking then proceeds by excavating in the centre of the curb, and finally the brick, which meanwhile is supporting the curb, is then cut away, and props are inserted as shown by fig. 61, the props usually raking inwards. They rest on footblocks, and must be made fast to the curb above. The process described is technically termed *underpinning*.

Where it would be deemed impracticable in unstable ground, drum curbs are substituted. They are shown in fig. 62, and are formed of cast-iron sections bolted together.

Having sunk the shaft to the required depth, that is, to the level of the soffit of the proposed tunnel, it has to be supported, because a shaft of the kind described is expected to descend by its own weight, although, by adversity of circumstances or indifferent engineering, they may resist all efforts to move them. The application of a water jet may remedy matters, but great care should be taken that a shaft sinks evenly, and does not get out of the perpendicular. The supports may take the form of sills and a cast-iron ring or curb, as shown in figs. 63 and 64. The sills are scarfed if very long, and have plates on the top. They are fixed in small headings large enough for a man to work in, the earth being afterwards rammed tight. Another method is to hang the shaft from the top. The hanging rods are usually made of iron, although wood, with scarfed or jib and cotter joints, has also been employed. Their sectional area must be proportioned to the load and the ultimate strength of the iron or steel used, allowing a factor of safety of 5–7. Figs. 65-67 show the usual procedure. Having secured the shaft, the work proceeds downwards with what is termed the square timbering. It is formed of square settings of timber about 6 ft. apart, and propped with rough timber one from the other, the space between being planked with 3-in. deals. The material generally used is what is termed "6-ft. deal ends." The earth must not be disturbed, and argillaceous shale (blue ground) should not be exposed to the air longer than necessary. The square settings must always be plumb under the shafts and square with the tunnel, the poling boards being inserted after the earth has been removed to admit them. Fig. 68 shows the procedure. When running sand is encountered, sheet piling is resorted to. It is called *sumping*, and the space enclosed must be smaller than the actual shaft. Another method of timbering a shaft is given in fig. 69.

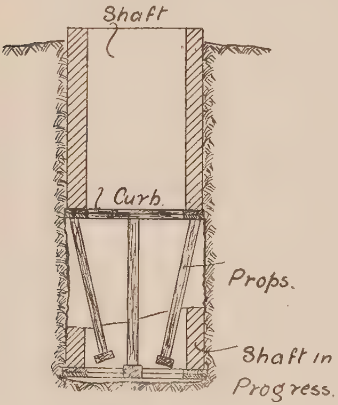


FIG. 61.

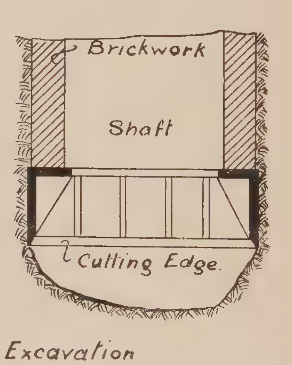


FIG. 62.

Having finished the shaft, it is necessary to transfer the levels and centre line to the bottom of the shaft before much of the heading can proceed. With a square or oblong shaft this may be done as follows. Referring to fig. 70, the line of the sewers should first be laid out on the surface of the ground, and pegs driven in to mark the intersection of the centre lines where the direction changes, and the centre of the proposed shafts. Before commencing the excavation for the shafts, permanent pegs should be driven in, and covered or protected in some way, at points about 6 ft. on each side of the centre pegs, along the centre line of the sewer, and

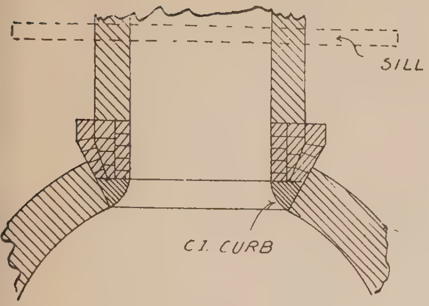


FIG. 63.

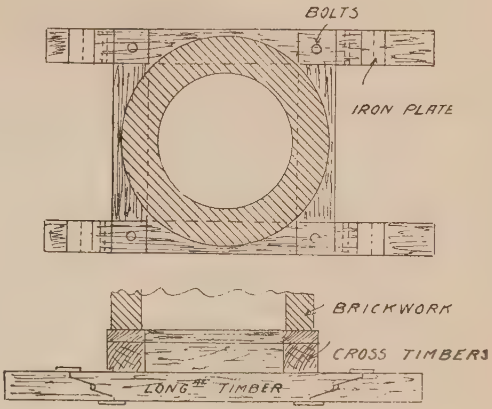
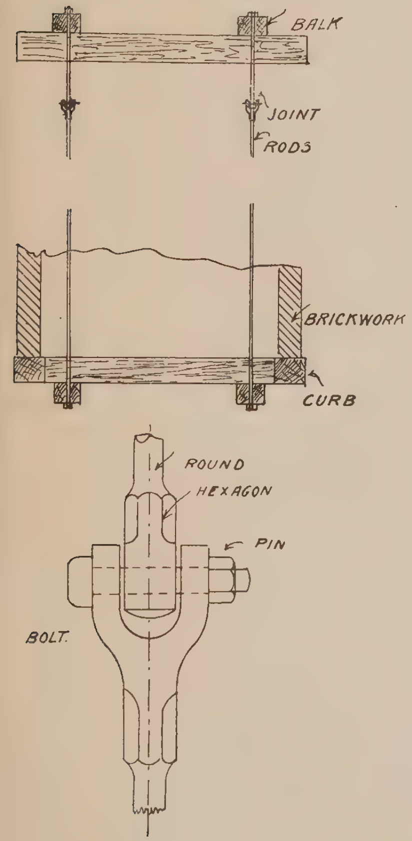


FIG. 64



FIGS. 65 and 66.

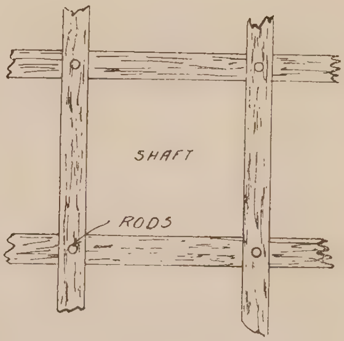


FIG. 67.

along the centre line produced where the direction changes. The exact centre line is indicated by a nail driven into the top of each peg in positions found by ranging the line in with a theodolite; or if no theodolite is available, by sighting it with ranging rods. The shafts, which should not be less than 9 ft. long, can then be set out and sunk. The centre line must then be again ranged in on the surface, and notches cut in the top walings of the shaft where the line cuts them, as shown in the accompanying illustration. A heavy plumb bob should be suspended from these notches, and nails driven horizontally into the bottom waling immediately below the notches. The line that is sighted through the cords of two plumb bobs suspended from these nails will then correspond with the centre line as set out on the surface, and will be the line on which to drive the heading. As the work proceeds, the centre line is ranged up the heading by using a third plumb bob, the position of which, when in line with the original two, is marked by a nail driven horizontally into the head-tree. A bench mark should be made in the bottom of the shaft near one of the corners by driving

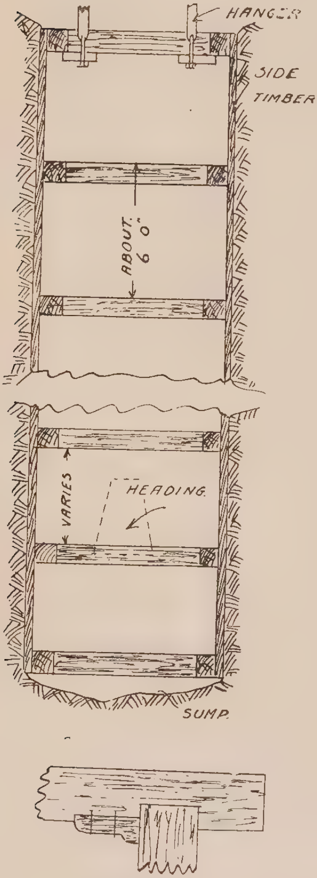


FIG. 68.

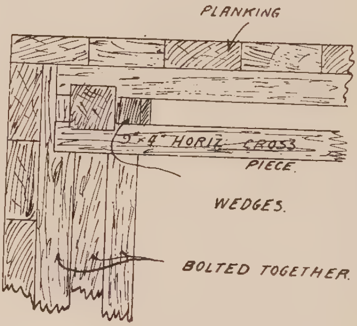


FIG. 69.

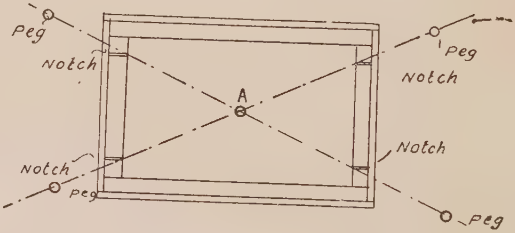


FIG. 70.

a peg firmly into the ground and protecting it from damage, the level of the top of the peg above Ordnance datum being found by levelling on the surface from an Ordnance bench mark to the top waling of the shaft, and then measuring down by a steel tape on to the peg. From this peg the levels will be taken in the usual way, and sight rails fixed by nailing boards across the side-trees, which should be notched level with the top boards, so as to at once show whether any accidental movement of the boards has taken place. There should be several sight rails through the heading, so that a check is obtained on any settlement of the timbering, or one may proceed as in fig. 71, placing the timbers shown at right angles to each other over the mouth of the shaft, one of which is in the direction of the centre line. Then, having fixed X in the centre of the shaft, the points 1, 2, 3, 4 are set out so that they enclose a square whose diagonals intersect at X; from holes in the timbers at these points plumb bobs are hung, by means of which the square 1–2–3–4 can be again set out below ground, two points being in the centre line of the sewer and the other two used for checking any error which would arise from one of the pegs getting accidentally disturbed.

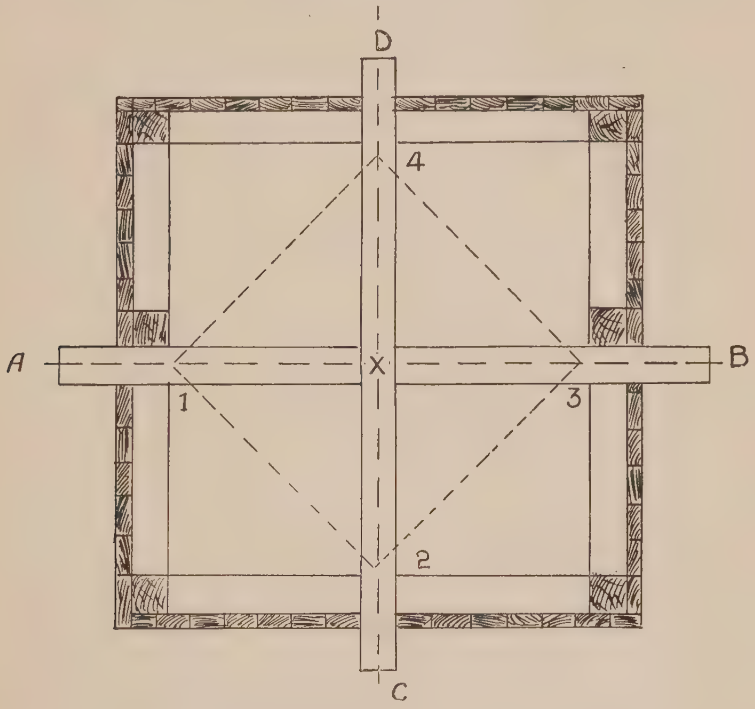


FIG. 71.

The more accurate method of procedure is, however, as follows:—

Two pegs, A and B (fig. 72), are very carefully ranged in the centre line, at such distances from the shaft as to be safe from disturbance. To mark the exact position of the centre line each stake has a spike driven into its head, each such spike having an eye through its top. The eye is then very carefully ranged in the exact centre line, being made visible to the observer by holding white paper behind it. A cord is then stretched through the holes in the spikes to mark the course of the centre line across the mouth of the shaft, and at each side of the shaft a plank is laid at right angles to the string, with its edge overhanging the edge of the shaft a few inches. Two plumb lines are then hung from the planks directly under the cord that marks the centre line. These two wires have plumb bobs at the lower end, which should rest in buckets of water to steady them; then, having made sure that the lines are anchored securely in the exact positions (special windlasses, having slow motion screws to adjust the line to right or left, being usually provided), the engineer takes his theodolite and proceeds down the shaft by means of a cage or ladder. While doing so, he must carefully observe every part of the two lines to see that they contain no kinks. When the bottom is reached the theodolite is set up at G in such a way that one wire appears directly behind the other—that is to say, the line of collimation should cut the two wires. In such a position the centre line below ground may be set out.

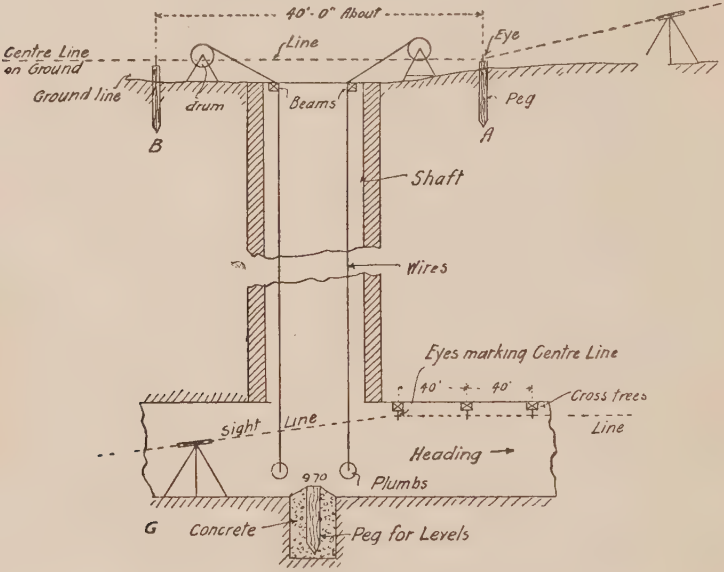


Fig. 72.—Alignment of a Tunnel.

The wires, and also the cross wires of the telescope, have to be illuminated by lamps, and the instrument should be provided with a special sliding adjustment in order to get into line with the wires exactly. When about 40 ft. of the heading have been driven in the direction of the arrow, blocks of wood having eyed spikes similar to those previously described are fixed to the cross-trees, these spikes being accurately lined in by the theodolite. A cord stretched between them gives the centre line to the underground foreman, the engineer checking it from time to time by the theodolite.

Having proceeded thus far, the headings would be commenced. They are started by an "adit," and usually take the form shown in figs. 73 and 74 when the ground is good. They are driven at the top of the invert level for the purpose of drainage. Where the heading has to be widened in its course, this is done by excavating at the top and inserting longwise on the ledge so formed a "crown bar," while another rests on props. Again, on the top of these go the poling boards. The side earth is now removed and the props inserted as shown in fig. 75. The crown bars are kept apart by struts, while the props rest on "footblocks." The next job is getting in the top, as shown by fig. 76, until a complete arched roof of timber is formed. For small pipe sewers, however, the form shown in figs. 73 and 74 is maintained, the tunnel being thus made from end to end of such a size that the men can conveniently lay the pipes therein. They usually vary in size from 5 ft. × 3 ft. to 7 ft. × 5 ft. The method shown consists of round upright props or side-trees, usually slightly inclined inwards, so that the bottom of the tunnel is somewhat wider than the top. These side-trees are usually 4 to 6 in. in diameter, according to the size of the framing, and are generally spaced 2 to 3 feet apart. The head is formed of similar timbering. The props should preferably rest on a sill, or they may

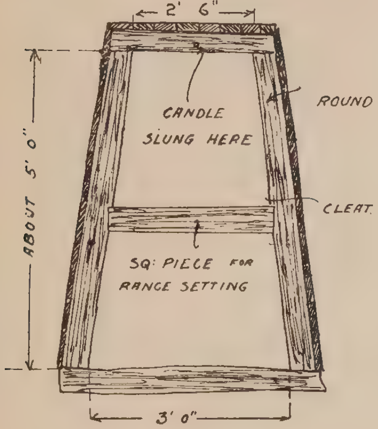


Fig. 73.

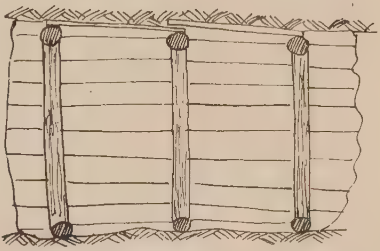


Fig. 74.

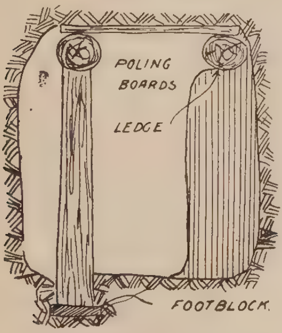


Fig. 75.

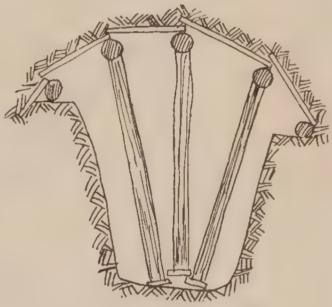


Fig. 76.

be merely sunk in the ground. The heads are then spiked to the props, while these are, in turn, secured to the sills by means of brobs. The timbering of a tunnel must always be adapted to the soil which it is to support. As much of the timber is usually left in the tunnel, it must be economically used, because even if it is removed it will hardly repay the cost of such removal. For loose or wet ground the system shown in fig. 77, consisting of a double frame, is used. The poling boards are held in position with square timber, this being supported, in turn, by an inner frame, and finally tightly driven up to the excavation by means of wedges. The forms of timbering just described, however, are of a needlessly heavy kind where the earth is very compact, such as stiff clay, chalk, and shale. In this case it is usual to support the sides by timber at intervals of a few feet, and the process takes the form of figs. 78 and 79.

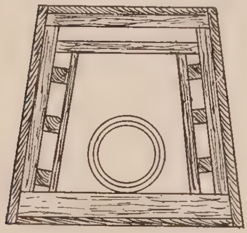


Fig. 77.

In any case when it is proposed to drive a sewer in tunnel, the nature of the strata through which it is to run must be carefully ascertained, and also by "drifts" along the proposed line of tunnel. The most favourable material, without doubt, is durable rock, not very hard, but this is very expensive to work and progress is slow. Quicksand and mud and other saturated positions are always the most treacherous, while, as before stated, certain clays soften on exposure to the atmosphere. Again, it must be remembered that in driving a mine through ground in which it is possible that cavities containing large quantities of water may be encountered, borings ought to be carried forward directly and obliquely in advance of the mine in order that the neighbourhood of such cavities may be ascertained in time to guard against sudden inrushes of water into the mine, and that the water accumulated in them may escape by degrees and without danger through a borehole. This precaution is especially necessary in approaching old pits, mines, or tunnels, which are often full of water. The heading

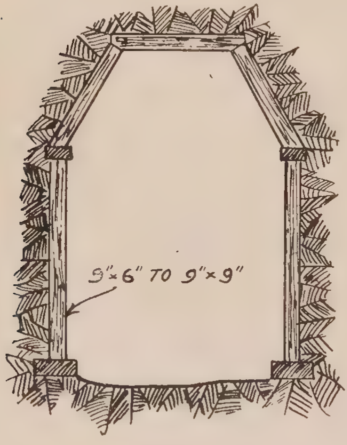


Fig. 78.

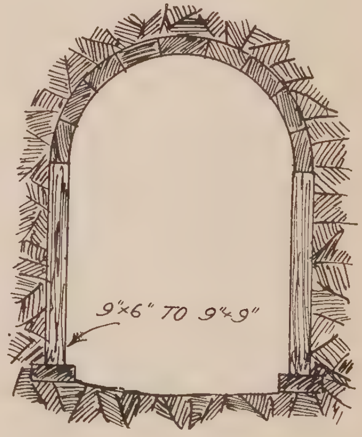


Fig. 79.

for a tunnel in solid rock is generally driven immediately below the intended roof of the tunnel, the excavation being extended sideways and downwards from the heading by blasting and quarrying; where, however, the rock is fissured in character, a brick or stone arch is usually required to prevent the roof from falling in. The heading is in this case driven close below the roof of the excavation, but the subsequent removal of debris is only continued downwards at the sides, thereby leaving a solid wall in the centre, which is used to support temporary props for the roof where required, and also the arch centres for large circular sewers, the work being carried forward immediately behind the excavation. This central wall, then, is not cut away till the arch is complete and the centres struck, the space between the brickwork and the rock being very carefully rammed with dry rubble or concrete, as shown in figs. 80 and 81. Another system of tunnelling, as applied to sewers, is shown in figs. 82 and 83, the profile of the sewer being shown in dotted lines. In fig. 82 the square heading is made about 3 ft. 6 in. × 2 ft. in section for 7 or 8 ft. or so, the central pole being of larch; the arch of the tunnel is then cut, the poling boards placed in

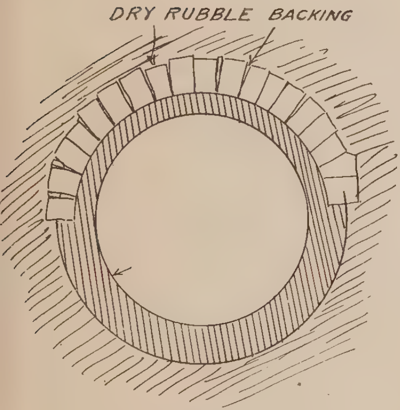


Fig. 80.

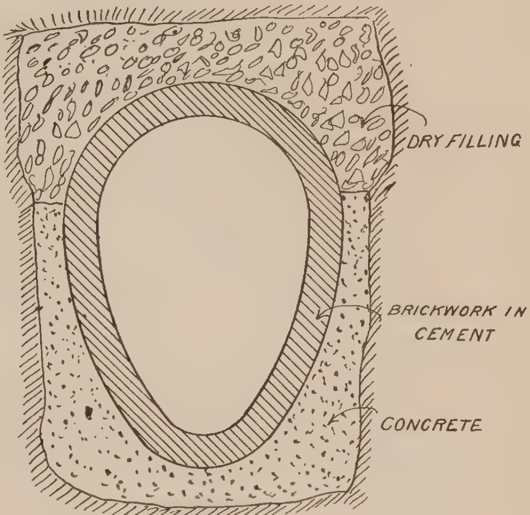


Fig. 81.—Sewer in Tunnel in Clay.

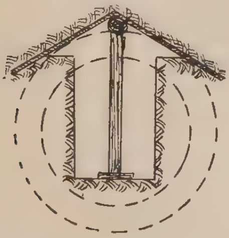


Fig. 82.

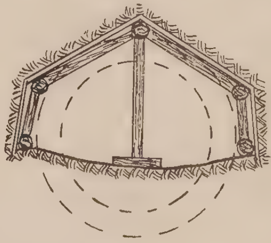


Fig. 83.

position, and temporarily supported by earth thrown into the heading. Fig. 83 shows a further stage of the process, and is continued till the brickwork which forms the foundation of the sewer is built up. When the arch has been built the poles are removed and the poling boards left, supported by the arch; but care must be taken that they bear equally on the brickwork. For very large sewers, 6 ft. in diameter and over, in fairly soft but dry ground, the work is carried on as shown by figs. 84 and 85. From the foot of the shaft the miner proceeds to excavate the tunnel, the upper portion being removed to a sufficient extent to allow the insertion of a sill about the centre line of the sewer. Props are then fixed upon this to support the crown bar and other bars, the poling boards which support the roof and sides being finally driven behind them. The lower portion is then left unsupported, and merely trimmed to the shape of the sewer, but this is only practicable in good ground; in bad ground the sill will need support by means of props fixed on to the sill of the invert. An extension of the foregoing system is shown in fig. 86, each member being named. When the top props, resting on footblocks, are covered with the poling boards, the excavation is carried down to the level of the footblocks, and the sill, which extends the whole way across the excavation, is inserted in two halves, which are joined by a scarf joint.

The props which support the horizontal bars are then inserted, and struts are placed abutting against this sill and the timbering of the shaft at the side. As the excavation proceeds, the raking props are inserted below the sill. They rest on footblocks. A lower sill is finally inserted, supported by struts and raking props in a similar way to the upper sill. The bottom of the excavation should be formed very accurately to receive the invert, which must be at the exact level shown on the plans. Any sewer or culvert carrying water or other liquid by gravitation demands that great attention should be paid to the accuracy of the levels, and special precautions must be observed in this direction.

The usual method of transferring levels down shafts is to determine accurately by the level a point marked on one of the guides in which the cage works at the top. The engineer then proceeds down the shaft in the cage, and very carefully measures, by means of a steel tape (whose accuracy at normal atmospheric temperature can be guaranteed), the distance to the bottom, where a similar mark is made. The measurements should be checked, and agree within a very small fraction of an inch. Sometimes the guides of the cage are of wire rope, in which case the measurements are taken on the side of the shaft. The tape must always be quite vertical. In fig. 72 a means of setting a bench mark in a tunnel is depicted. Bench marks may also be formed by wedges or spikes in the side of the tunnel, set at a convenient height, and marked by a painted arrow thus, ⊼. As the heading proceeds, the engineer extends the centre line and the levels from time to time. A special short tripod may be required for this purpose, and a more finely divided staff than used above ground. Needless to say, the work must be very carefully done, especially in the case of brick sewers, where the profiles which guide the bricklayers have to be carefully set to the required level by the engineer by directing them to be raised or lowered in reference to some permanent underground bench mark. The level of these profiles should be checked some distance back in the finished sewer.

Cast-iron Tunnel Lining.—When the ground under which a large sewer is to pass in tunnel is very bad, various methods are resorted to in order to execute the work safely and economically. The generally accepted method is now the system of cast-iron segments, lined inside with concrete, similar in a way to the system adopted in "Tube" railways.

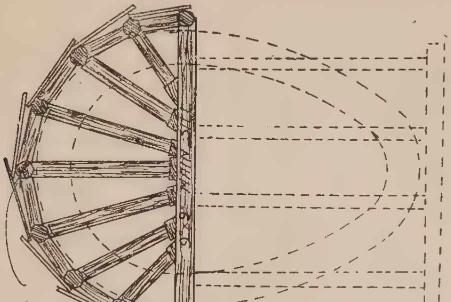


FIG. 85.

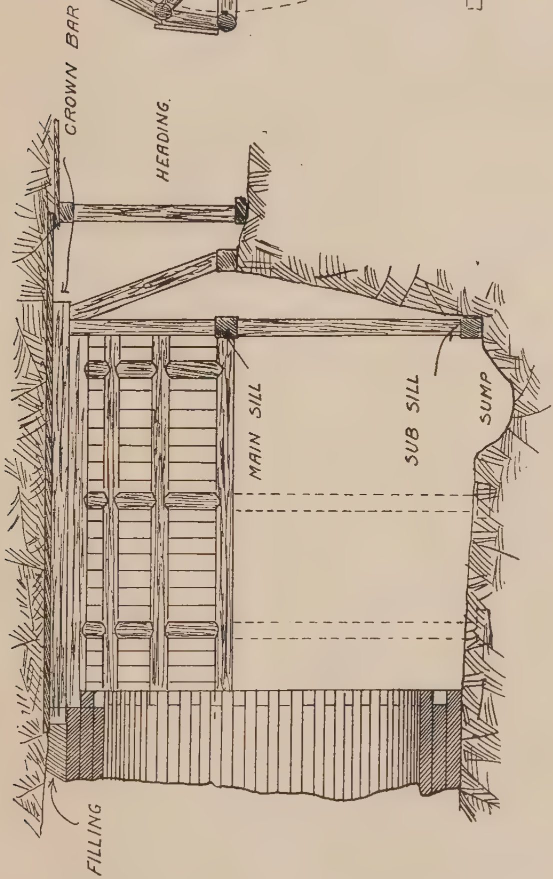


FIG. 84.

This system is specially useful for taking sewers under rivers and other subaqueous work. The tunnel is driven by means of a shield, the best known form being the Greathead Shield, in conjunction with a system of compressed air. The full details are described in most works dealing specially with the art of tunnelling, and it would be out of place to go into such details here.

Briefly, however, the apparatus consists of a cylindrical bulkhead, a little larger than the finished outside diameter of the sewer. The front is formed by means of segmental steel castings, thus making a conical cutting edge. The tail of the shield is made up of steel plates which are fixed to these castings. This shield overlaps the actual tunnel for a short distance, in order to support the excavation sufficiently far back to enable the cast-iron lining to be fixed. The shield is fitted with horizontal and vertical diaphragms, and a vertical plate diaphragm is fixed behind the castings, in which are suitable doors for the entry and exit of men, and exit of the material, which may be removed by hand or by special mechanical means. Hydraulic rams, bearing on the finished portions of the sewer, serve to drive it forward. The pressure within the shield *may* be as much as 35 lb. per sq. in., but at such a high pressure risk of sickness amongst the men is very great. Inverted syphons under rivers are usually driven in this way, because by the use of compressed air they may be driven within a few inches of the river-bed; but in this case it is necessary to pump the water from a central sump, either by a pump at one of the shafts having a long length of suction pipe, or by a pump fixed at the sump with delivery pipe to the ground-level. A subsoil pipe is usually laid under the sewer to carry off the water to a shaft at the bank at its lowest end, from which it may be pumped. In laying such a pipe in sandy soil, it is advisable to lay a chain inside it, to agitate the sand, and prevent the pipe being filled up. In other cases it is at times necessary to build a pipe in the side of the sewer to drain off the water from behind during construction, the pipe afterwards being plunged and made good.

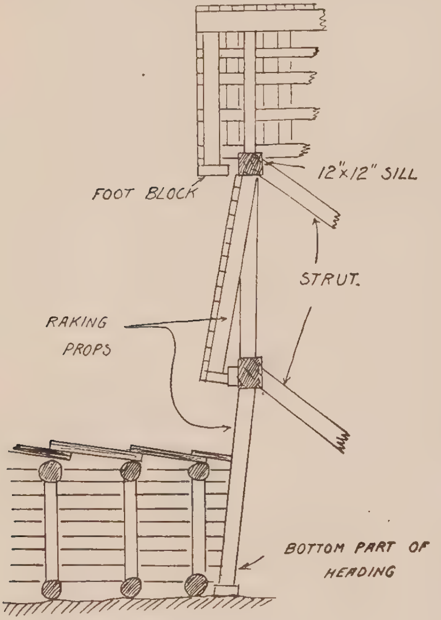


Fig. 86.

In longer and larger tunnels it may be necessary to drive separate drainage headings, but generally the water finding its way into the tunnel will be allowed to gravitate to the lowest shaft, and then be pumped to the ground-level or run to the outfall.

The system is shown diagrammatically in fig. 87. It is, of course, not essential that such a cast-iron sewer should be lined with concrete, and made a channel for the passage of sewage itself; it may be a dry culvert carrying pipes conveying the sewage, but this is more applicable to waterworks practice than sewerage. The section of such a cast-iron sewer is given in fig. 88, in which such pipes are shown by dotted lines supported on a cross beam of wood, with a gangway between them. The tube is composed of cast-iron plates 2 in. thick (the thickness varies according to the pressures they will have to sustain), and having flanges 12 in. deep and 2 in. to 3 in. thick, according to the thickness of the tube. In this case each ring is 2 ft. 6 in. long, and built up of 14 segments, with a solid key on the top. They are shown in detail in figs. 89 and 90, while the key is shown in fig. 91. It is taper in shape, being smaller at the top than the bottom, so as to be inserted easily, the contiguous flanges being specially formed to suit it. All joints, whether horizontal or circumferential, are machined, the recesses inside being sometimes formed for caulking purposes. The plugs are for the purpose of forcing cement grout behind the plates under pressure, in order to fill up the vacant space between the plates and

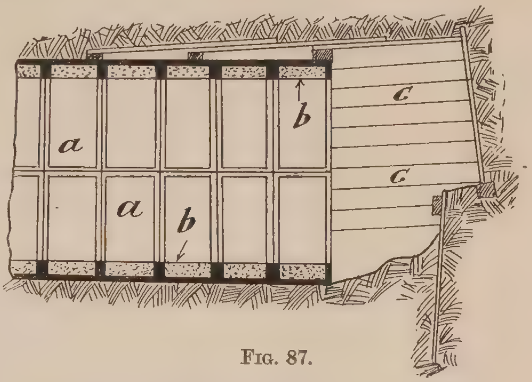


FIG. 87.

a a. Cast-iron segments; *b b.* Concrete lining; *c c.* Poling boards.

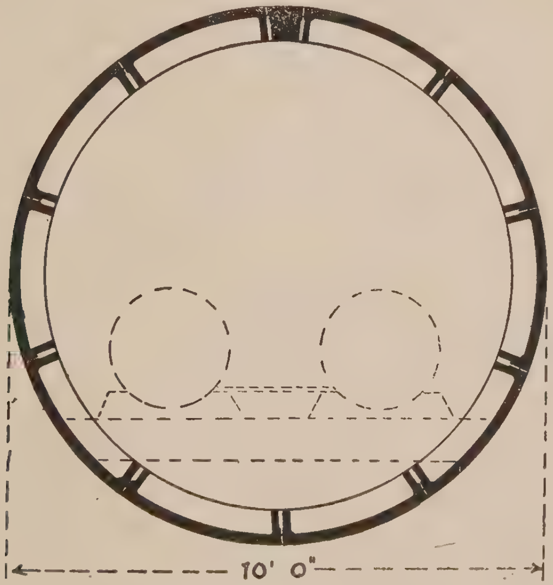
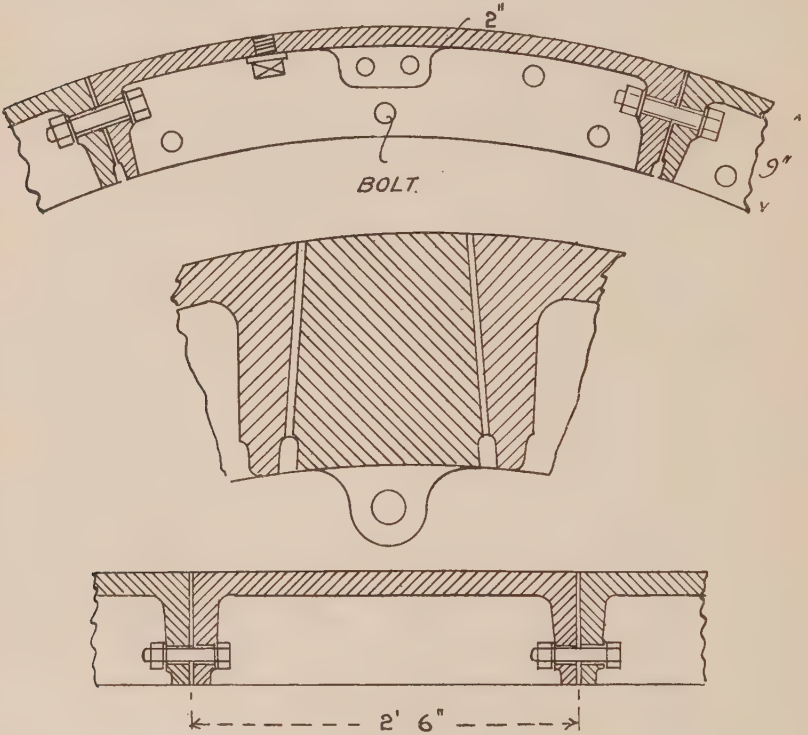


FIG. 88.

the excavation. They are tapped to suit the holes, and are inserted when the grouting is done. The shield is fixed so that its tail surrounds the last ring of the lining which is put in place. The following ring is then erected inside the tail of the shield, which is pressed forward by the rams as the work proceeds. As the segments are sometimes very heavy, a hydraulic erector is often employed for putting them in place. In the St Clair River tunnel in New York the abutting surfaces of the radial joints of the segments are planed and packed with packing pieces of $\frac{3}{16}$th in. white oak, which after the bolting up gets wet, swells, and makes a very tight joint. Tarred canvas is used in a similar way for the circumferential joints. This system of having the flanges machined very accurately is a great help towards subsequent true alignment of the tunnel, because each one added is, to a certain extent, fixed by the previous one. The wood packing referred to, then, is useful in correcting any errors, because, if the last ring is too high or too low, the top or bottom may be packed up, as the case may be. But the engineer must test the last executed ring for centre line and level before ordering the packings. This testing is done by stretching a line across the tunnel from the bolts of the segments. A plumb line is then ranged in, and by means of a tape, which is laid horizontally across the diameter, the measurements will show any error, and its magnitude. A



Figs. 89–91.

steel tape should be used. The flanges of the segments are convenient points for bench marks. The method of alignment is shown diagrammatically in fig. 92. As an example of tunnel work, the following description is taken from the *Proc. I.C.E.*, vol. c.:—

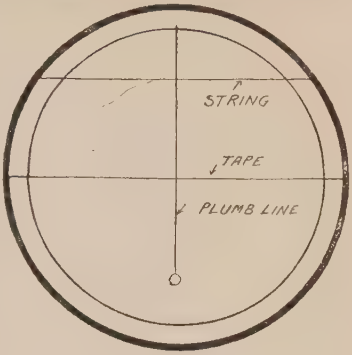


Fig. 92.

"Aqueduct.

"The total length of the aqueduct, from the intake works at Mii-mura to the filter beds and service-reservoir on Nogeyama, is 27 miles.

"The hydraulic gradient of the first 18 miles, to the summit of the Katabiragawa watershed, is 6 ft. per mile. At this point the diameter of the main pipe is reduced from 18 in. to 15½ in., and the hydraulic gradient of the remaining 9 miles is 14 ft. per mile.

"Commencing at the basin below the gauge at Mii-mura, the aqueduct follows the left side of the deep cañon of the river Sagami for a distance of 7 miles, and consists of alternate sections of 18-in. cast-iron pipes, and of short conduit tunnels, which pierce the more projecting spurs of rock that abut upon the river.

"In five cases tunnels were driven at levels below the hydraulic gradient for the reception of the main pipe. The tunnels on the hydraulic gradient are sixteen in number. All are 4 ft. 6 in. by 4 ft. 3 in. in cross section, and are generally unlined, the bottom being roughly dressed with the pick. In a few places, where the rock was unsound, or the tunnels were cut into the gravel beds that mark the margin of the river at its ancient levels, brick-in-cement lining was resorted to. Small brick-lined wells, sunk below the floor-level, were constructed at the upper and the lower ends of every conduit tunnel. The intermediate sections of main pipe were connected with these wells, and governed by valves on the lower extremities of the sections. The wells were provided with sluices and overflows.

"As a preliminary to laying the main pipe in this upper portion of the aqueduct, a road, following where possible the hydraulic gradient, and wide enough to carry the tramway and a row of pipes alongside, was constructed by cutting a benching along the precipitous wall of the river. The driving of the tunnels was proceeded with at the same time; for which work dynamite was extensively used, the drilling being done by hand.

"When the road was finished, the 'Decauville' tramway was laid down, and the pipes were transported along it, through the tunnels, to their places. The pipes were laid in a trench, for the most part hewn out of the rock, along the inner side of the roadway. The sinuous course of this part of the pipe-line necessitated the introduction of an unusual number of special bend-pipes, and of short straight lengths. For this purpose an accurate survey of the route was made to a large scale, upon which the bends were marked. They were reduced to typical classes, namely, 25 ft. radius, 50 ft. radius, 30°, 45°, 60°, and 90° bends, and the trench was set out to suit these types. The quick bends were formed with the bend near the socket end, and had straight spigot ends to facilitate jointing."

CHAPTER V.

FORMS OF SEWERS.

In the previous chapter various methods of construction were discussed. The methods referred principally to the formation of a suitable foundation or bed on which the sewers would be laid. It is the actual sewers, their variety, mode of laying, and construction, and the materials composing them, that will receive consideration here.

The early engineers had vague ideas of what constituted a sewer, especially bearing in mind the principles set forth in Chapter II. Up to comparatively recent times, "misled by an instinctive adoption of the works of our forefathers, we have been content to build our sewers in old channels, and to put patch upon patch—add length to length of sluggish sewer, or practical cesspool, in order to maintain ancient outfalls; while the subsidiary details of form and capacity have become the vexed questions and grounds of issue among the most practised advisers."[1] Again, it was quite a common idea that all sewers should be large enough for a man to crawl in for the purpose of cleaning them out. This entailed the use of a sewer at least 2 ft. wide × 2 ft. 6 in. high. The old form of sewer, which survives even to the present day, is that which consists of a flag bottom, dry rubble-built sides, and a flag top. Obviously nothing could be worse, because, by reference to fig. 93, it will be seen that no matter what fall the sewer had, the wide bottom would collect silt, to say nothing of the escape of sewage through the usually open joints and the escape of bad air through the top. Many drains of this kind exist under houses at the present day. Brick is sometimes found forming the sides. The dry built circular culvert is little improvement on the former methods. They are to be found built of brick and stone, usually with open joints. Mr Dempsey refers to sewers in Nottingham, built of brick in this way, with the lower half dry and the upper half in mortar. The reason for this construction is not stated; presumably it is to attract subsoil water to swell the volume. In Bristol the elliptical sewer was in vogue, with a ratio of major to minor axis of four to three. Sometimes the top flag in fig. 93 was replaced by an arch. A modification of the egg-shaped sewer was tried in Holborn and Finsbury in 1843, having a very flat invert, however; but why this form of sewer, turned upside down, was used in Harrow the author has not the

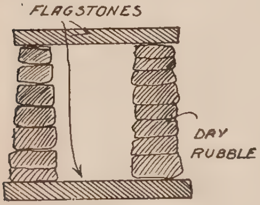


Fig. 93.

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[1] G. D. Dempsey on *Drainage of Land, Towns, and Houses*, 4th ed.

faintest idea, especially in view of the invert being found in parallel strips longitudinally, of brickwork and cement concrete. To even the most elementary engineer, the defects of the foregoing constructions are obvious.

Pipe Sewers.—For small and moderate-sized sewers, the pipe sewer, cylindrical in shape, is the best. Pipes are usually made of fireclay or stoneware, and often of concrete, with or without reinforcement.

In drain pipes there are great differences in quality, and sometimes it is a matter of doubt whether the pipes laid are actually of the class specified, and for this reason it would certainly be useful to engineers, architects, and others if manufacturers stamped their goods according to the class to which they belong.

It is not practicable to have a competent clerk of works on all drainage work who can reject inferior pipes before they are laid and jointed, so that the engineer may often see only the outside of the pipes when inspecting the work, and awkward differences of opinion may arise with contractors as to the actual class of the pipes laid.

Many fireclay drain pipes are very unsuitable for house drainage owing to their being bent, cracked, burred inside, untrue in section, making good jointing impossible, porous, insufficient size of sockets for the gasket and cement jointing, no glaze in sockets, etc.

"Common" Scotch "salt-glazed" fireclay drain pipes are very good for certain purposes where a uniformly smooth bore and impervious glaze are not of great importance; but it would be quite a mistake to use an inferior class of fireclay pipe for a house drain, especially where it is laid under the building, and this in many town houses is unavoidable.

It must also be remembered that the sanitary authorities of most towns do not permit new drains to be covered in until their surveyor has tested and approved them, and the use of inferior pipes would often lead to failure under test.

The common fireclay pipes have usually a "salt-glaze," which gives a fairly smooth surface in pipes made from ordinary fireclay; but if ironstone exists in the clay, it runs in the firing and makes "burrs" in the pipe.

The "salt-glaze" is made by throwing salt into the kiln and fires when a certain degree of heat is attained.

A suitable class of drain pipe is the "extra-glazed" fireclay socketed pipe. It is well suited for all ordinary drains and sewers of moderate size when made from a good fireclay free from foreign matter, and when well made, straight and true in section, not less than $\frac{3}{4}$ in. thick in 4-in. to 6-in. pipes, sockets at least $2\frac{1}{2}$ in. long and made parallel with the barrel of the pipe, so that the weight of superincumbent earth may not fall on the outer edge of the socket, as in cases where the sockets are tapered. The latter defect becomes more important when the drain is laid on a concrete bed, which is the practice in good work, and if the pipes are not "cradled" with concrete between the sockets to distribute the weight evenly.

These pipes are generally made in 3-ft. lengths, but are also supplied in 2-ft. and 2-ft. 6-in. lengths, and can be easily cut by a skilled labourer.

Fireclay sewer pipes are made from the finely ground and tempered fireclay, by being pressed by steam-driven revolving "knives" through a cast-iron cylinder, to which is attached a polished cast-iron "die," suitable to the size of pipe wanted for the time being.

The pipes, when sufficiently "stiff" to handle, are finished, and the "slip" glaze (which is composed of fine, dense, vitreous clay, with a mixture of flour-glass and other ingredients) is poured through them, thereby giving them an internal coating of the mixture.

The strength of this "slip" is nicely adjusted to suit the fireclay body, so that when the slip is vitrified by the intense heat in the kiln, it forms a smooth, glassy surface inside, thoroughly incorporated with the body of the pipe. This process produces a strong straight pipe, smooth inside, non-porous, not deteriorated by sewage or the test of time, and greatly superior to the common salt-glazed pipes.

The following is the analysis of the fireclay from which these pipes are made: silica, 57·35; alumina, 38·60; oxide of iron, 1·85; lime, trace; magnesia, 1·22; potash, 1·44; soda, 0·96–101·49.

It is obtained from the coal measures, and is admirably adapted for the manufacture of drain pipes.

Stoneware Pipes.—Stoneware pipes are frequently used, but they are somewhat brittle, which renders cutting, in the hands of an ordinary workman, almost impossible. Stoneware is harder and closer grained than fireclay, and consequently less porous; but, owing to the drawback mentioned above, they do not appear to be much in favour where the best fireclay pipes are available.

The sockets are often too small for efficient jointing in the smaller sizes, and they are only made in 2-ft. lengths as a rule, which means an undesirable multiplication of joints in a drain. The price is higher than for fireclay pipes of the best quality.

Stoneware is the name given to[1] "articles made from the plastic clays of the lias formation, obtained chiefly in the South of England. The best comes from Poole in Dorsetshire and from the vicinity of Teignmouth in Devonshire. It is generally mixed with certain proportions of powdered stoneware, ground and calcined flints, ground decomposed Cornish granite and sand to prevent excessive shrinkage. The pipes are burnt in domed kilns like fireclay goods, but at a very much higher temperature. A fractured surface shows that this ware is thoroughly vitrified throughout. It is intensely hard, dense in texture, close in grain, and rings well when struck. It is admirably adapted to all purposes where strength and resistance to atmospheric or chemical actions are required, and it is its strength, durability, imperviousness and resistance to destructive influences which make it an admirable material for sanitary ware." The pipes are often salt-glazed, but the material is in itself non-absorbent, and will resist the effect of moisture even when unglazed. Messrs Sutton & Co., Ashby-de-la-Zouch, who are very large makers of stoneware pipes, state in regard to them that—

"Tests by Messrs Kirkaldy & Son show an average absorption after twenty-four hours' immersion of only 0·2 per cent., whilst in the thrusting stress test the average stress borne by 18-in. pipes was 7651 lb. and by 9-in. pipes 5874 lb.

"These pipes have also been tested up to 200-lb. pressure to the square inch without bursting or showing signs of leakage.

"Chemical tests made by Dr Muter, F.R.S.E., F.I.C., F.C.S., public analyst to several of the London districts, the administrative county of

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[1] *Notes on Building Construction*, vol. iii.

Lindsey, Lincolnshire, and the Metropolitan Asylum Board, show the material and glaze of our pipes to be the best quality."[1]

Strength of Pipes.—In order to secure permanency and durability of sewer work, great care is required in the selection of a proper material, the best invariably proving the cheapest in the end. The inverts of sewers are subject to constant wear by the grinding action of sand and other heavy matter rolled along by the water. Again, the materials used should be those which are least affected by the chemical qualities of the sewage. In selecting sewer pipes, especially for deep trenches, a good thickness of material is essential. Thickness for thickness, stoneware pipes are stronger than ordinary fireclay, but are not so smooth inside, and will not take a salt-glaze finish. Fireclay pipes, when they get thoroughly saturated in a deep trench, will actually squeeze out of shape if too thin and not very well burnt. The best quality of pipes are those made of a vitreous material, which is imperishable and of sufficient strength to resist shocks. It should be tenacious, hard, impervious, and homogeneous in character, and the pipes should be true in thickness and uniform in section, perfectly straight, evenly glazed inside and out, and free from cracks. A good pipe, if struck, will give a clear metallic ring. Some pipes are faulty by reason of the glazing having run and formed ridges inside at the spigot end; such pipes should be rejected, because this may subsequently cause a stoppage. Some pipes are lead and glass glazed. They are not so good as salt-glazed pipes for general work. If a sewer pipe is impervious, it will generally be a good one for the work, as impermeability bespeaks hard vitreous material, burnt at a high temperature. By being impervious to water, it is not so likely to be damaged by frost or by the chemical action of the sewage. Pipes may be tested for permeability by weighing them when quite dry and after 24 hours' immersion. The difference is the water absorbed. It should not exceed 5 per cent., and good pipes may absorb as little as 1 per cent. Doulton's pipes usually absorb less than 1 per cent., being especially dense. If a pipe is porous, water will cause a sweat on the outside when under test, or if it is stood on end and plugged and filled with water. Fireclay or stoneware pipes lack tensile strength, and must not be used under pressure internally. The writer has known sewer pipes to stand a pressure of 80 lb. per sq. in., but the material is very unreliable, and this is quite an exceptional instance. Another strain which sewer pipes may be subject to is that of careless filling in of the ground, which by rights must be done in layers and carefully rammed. For this reason, and also that the filling of the trench is continually tending to crush them, a good thickness is very essential. Sewer pipes may be tested for crushing strength, which is of value in the following manner. Referring to fig. 93A, pressure is applied by the weighted lever as shown, the pipe resting on and the pressure bearing on two *flat* pieces of wood. With modern pipes the breaking weight will be found to be between 2700 and 3000 lb. in most cases. Very special pipes may show as high as 3500 lb., the larger diameter pipes showing a higher load than the small ones as a rule. Another very important point is the socket of sewer pipes. Defective sockets are a prolific source of leaks. Most makers do not give sufficient depth for the joint; in other cases the material is very thin in the socket; while the worst practice of all is that of making the pipe and socket separately and working them together. On the other hand, many sewers have failed by laying the pipes on the concrete bed and not cradling them with concrete between the sockets, which is sheer neglect on the part of the engineer or clerk of works. The result is, the whole strain comes on the sockets, and failure is not to be wondered at under such circumstances. The old practice of leaving recesses in the concrete bed has been discarded. Not only did it break the continuity of the concrete, but it was often found that the pipes were not all of uniform length, and that when laying commenced, the recesses were in the wrong place. When a sewer pipe gets broken after laying and jointing, its replacement is often difficult and unsatisfactory. At least three pipes have to be removed, and a strain is likely to be set up in some of the other sockets, especially where Stanford joints are employed. In cases of this kind the writer is inclined to favour the use of a saddle junction, or, as it is sometimes called, a collar joint. They must not be used elsewhere, as they do not make a good joint, but their use in this case is better than risking failure of some of the good ones.

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[1] Catalogue of Messrs Sutton & Co., Ashby-de-la-Zouch.

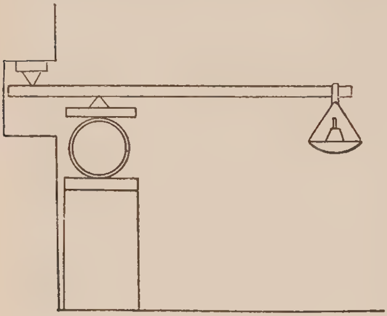

FIG. 93A.

Iron Pipes.—Cast iron must be used for all sewers in which there is likely to be any internal pressure. Pipes over 6 in. in diameter are usually cast vertically. The socket end may be cast upwards or downwards as required, the latter being the most usual practice. Vertically cast pipes are in all respects superior to those cast horizontally; if large pipes are cast in the latter way the core is apt to float, with the result that the thickness is not uniform. The same thing may result if the core is not placed truly concentric, or if it warps in the drying process. Again, if the pipes are cast horizontally, core nails are required for fixing the core in position, and these are subsequently hammered up; pipes can thus be easily detected if cast horizontally. It is essential that the engineer should rigorously inspect any cast-iron pipes used by him. They should be truly cylindrical; all spigots should fit properly into the sockets; all specials should be properly shaped; and join the straight pieces correctly. The section of every pipe should be truly concentric; any deviation of more than $\frac{1}{4}$ the specified thickness should be a reason for rejecting the pipe.

The average tensile strength of cast iron may be taken as 7 tons per sq. in.; the safe load should never exceed $\frac{1}{10}$th the breaking weight. There are formulæ for the proper thickness, based on the above assumption, but it may here be stated that if a pipe has a thickness which is sufficient to allow of it being properly cast, then it will be likely to stand any ordinary pressure to which it will be subject in practice. All cast-iron pipes are made of considerably greater thickness than that required to ensure their stability when subject to a given bursting pressure, because cast iron is slightly porous, and liable to considerable defects in casting when the metal is too thin. The resistance which a pipe offers for every inch of its length to the internal bursting pressure is equal to that of the cohesive strength of the thickness of its two sides, while the effective area of pressure upon the pipe tending to cause rupture is equal to its internal diameter.

The tensile strength of cast iron is usually taken at 15,000 lb. per sq. in.; and if the weight of a cubic foot of water is taken at $62\frac{1}{2}$ lb., the thickness of any pipe is simply a measure of the head and diameter

$$=\frac{62{\cdot}5\ DH}{2\times 144\times 15000}=0{\cdot}0000144\ DH;$$

and as the safe pressure should only be $\frac{1}{10}$th the bursting pressure, this formula becomes

$$0{\cdot}000144\ DH,$$

H being the head in feet,
D being the internal diameter in inches.

Concrete Bed.—Fireclay and stoneware pipes are laid on a bed of concrete. In hard ground some engineers lay them direct on the bottom, with holes cut to receive the sockets; but there is no apparent advantage in the system, and a good bed of concrete is to be advised. It should be the full width of the sockets plus 2 in. on each side, and be composed of 5 parts of clean gravel and sharp sand to 1 of best quality Portland cement, finished to a hard surface and laid to the proper gradient. A section of the pipe so laid is shown in fig. 94, and after testing with water, concrete is packed underneath the pipes and up the sides to half their diameter as shown, a process known as "cradling." The object is to take the strain off the joints which would occur by reason of the load on the top of the pipes due to the earth. It is an important precaution which must never be omitted, because if it is, the joints will be sure to leak after a time. It is one of those small points which unscrupulous builders like to omit, because, after inspection of the joints under test, the ground is filled in, and the cradling very conveniently "forgotten." An engineer must always see the work done before filling up the trench, and it should be nicely trowelled off, and not pitched in any way.

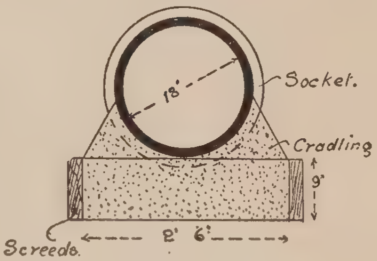

Fig. 94.

Joints.—The joints of the pipe should be made as follows: When the bed has been truly set to the proper gradient by means of boning rods, etc., described in a previous chapter, the pipes are all laid, with sockets facing the flow. They are then set truly concentric with each other by means of tarred gasket carefully packed into the sockets. Then a mixture of neat Portland or Medina cement is carefully packed into the joints likewise and trowelled off. It must only be mixed in quantities enough for 2–3 joints at a time, and no water added after mixing. The inside of each pipe is carefully scraped to remove any loose cement. When a length of pipe has been laid it must be tested as follows: Obtain a screw or bag plug and insert at the lower end. At the upper end place a bend in temporarily with cement, the socket being turned upwards, then fill up the pipes till they will hold no more water, and wait till all the air has escaped, when the water should stand quite steady. If it does not, a leakage is occurring; it must be found, rectified, and the process completed. It is most essential that the engineer see all this done himself.

Medina Cement.—Medina cement, which is often used for sewer pipes, is made by calcining nodules found in Hampshire and the Isle of Wight. They contain 30–45 per cent. of clay, and before being burnt have a fine, close grain and a pasty appearance. When broken they have a greasy surface. They are burnt at a low temperature, which is a process requiring much care. When calcined the colour of the stone is a rich cocoa brown. Besides the clay, the nodules contain about 10 per cent. of iron oxide and 40 per cent. of lime; they are known as "septaria," which are flattened masses of clayey matter showing crystalline seams. Good Medina cement should not weigh more than 75 lb. per bushel. It sets very quickly, but is not very strong. In order to test its strength and the variation thereof with age, the author conducted a few tests with the following results:—

TABLE XVII.

	Lbs. per sq. in.
7 days . . .	207
14 ,, . . .	304
21 ,, . . .	304
30 ,, . . .	305
3 months . .	431
6 ,, . . .	401
9 ,, . . .	427
1 year . . .	466

N.B.—Note the fall in strength of the sample at six months.

It is probable, from the examination of old Medina in sewer pipes, that after two or three years there is a falling off in strength. In a large contract it is wise to add a clause specifying the weights of Medina cement used, because the usual standard weight is 75 lb. per bushel; if heavier it may possibly be overburnt, or, what is equally bad, have been exposed to the atmosphere. Being sold in the ground state, it must be stored in dry casks, or else it will absorb CO_2 from the air and become useless. The casks generally contain 238 lb. of cement, viz. 3½ trade bushels of 68 lb. each; a sack contains only 3 bushels.

Patent Joints.—It is with the object of dispensing with the use of gasket as a jointing material, and also ensuring true alignment of the pipes, that the various patent joints are now on the market. First and foremost is the Stanford joint shown in fig. 95.

Briefly, the system consists in casting upon the spigot and in the socket of each pipe rings of a durable material, composed usually of a mixture of coal-tar, sulphur, and finely ground pipe. The result is a joint on the system of a turned and bored water main, which is a mechanical fit, and quite water-tight. The bands of composition are wiped over with oil and gently tapped home. The remainder of the work should be finished with Medina or Portland cement. There are many patent joints now on the market; those which are simple are no doubt efficient. Hassall's is a well-known form and is shown in fig. 96. Liquid cement is run in the hole provided. The composition is similar to that of the Stanford joint. In fig. 97 is shown Hutchinson's patent pipe made by the Bourtreehill Company. It simply consists of an inner lip on the socket, which is made a running fit on the spigot end. It eliminates the use of gasket and secures the alignment of the pipes, but ordinary cement is used. Yet another form of patent joint is shown in fig. 98, known as Smith's patent iron-jointed pipes.

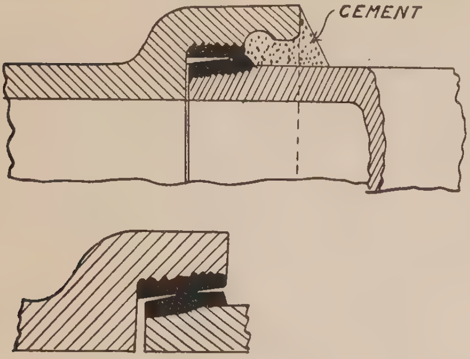

Fig. 95.—Stanford Joint.

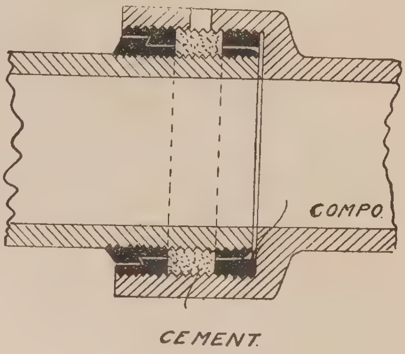

Fig. 96.—Double Seal Joint.

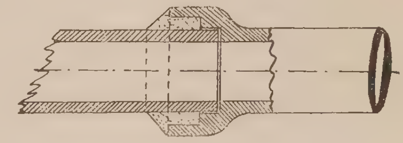

Fig. 97.—Hutchinson's Joint.

These pipes have a stoneware body with an iron socket and spigot, which are fastened to the stoneware by a very adhesive imperishable cement. After the spigot of one pipe has been inserted in the socket of the next, a strip of lead, supplied with the pipes, is placed around the spigot and driven into the socket with a caulking tool, making a very strong water-tight joint.

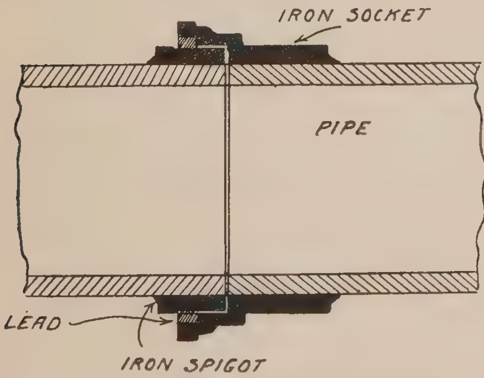

Fig. 98.—Smith's Patent Pipe Joint.

Smith's patent pipes are particularly suitable for sewers, where otherwise iron pipes would have to be laid at a much greater cost, as they combine the advantages of stoneware for the invert, thus avoiding corrosion and its consequent evil, with the security of the iron lead-caulked joints, whilst the iron fittings round the ends of the stoneware pipes add considerably to the strength thereof; they are made by Suttons' of Ashby. All sewer pipes should be inspected when they arrive on a job before being placed in position. In all cases they should be formed of imperishable vitreous material. They should be strong enough to withstand fracture, tough enough to resist shocks, tenacious, hard, impervious, of true bore, uniform in thickness, and perfectly straight longitudinally, although admittedly fireclay pipes do not always come up to these latter requirements. Again, they must be free from fire-cracks and flaws of all kinds, and be uniformly glazed. When struck they should ring clearly. The sockets should be deep.

Concrete Pipes.—For all work up to 18 in. in diameter, pipes are to be advised. Above this, neither fireclay nor stoneware pipes are very satisfactory, although much used, because sewers of brickwork under 24 in. in diameter are not generally built. Great advances have been made lately with concrete pipes, that is, without reinforcement, as opposed to large sewers constructed in monolith, which will be described later. In order to make pipes of concrete of sufficient strength and density, special methods have to be employed ; one system used is known as the Jagger patent process. It is described by the patentees as follows :—

" In this process the weight of the component parts of the concrete, acted on by gravity and the momentum of the moving mass, takes the place of the usual method of pressure or punning to compress the particles, but it also has the great advantage that air-bubbles and superfluous moisture and impurities are, by the motion given, brought to the surface in the form of slimes, where they are readily removed.

" Thus a rapid solidification of the particles takes place before the ' initial ' set of the cement occurs.

" The mass becomes homogeneous and equal in density throughout, and entirely without air-holes, cavities, or stratification of any kind, and that drawback to concrete faced work, the ' hair-crack,' is absent.

" The oscillation and vibration of the concrete, as it is fed into the moulds or forms, is produced by placing the said moulds on tables, which are given the required motion by a simple and inexpensive system of eccentrics. The wear and tear of the tables is merely nominal, and the power required to produce the small motion some three effective H.P. per table, carrying seven tons of concrete articles."

The advantages claimed are—

" 1. In the great density of the concrete product and its consequent imporosity. The various motions of the Jagger table, on which the concrete is made, all acting simultaneously, produce a concrete in which the aggregates are bound so closely together, with so perfect a combination and covering of cement, that air-holes and cavities are entirely eliminated, and an absolutely homogeneous mass of concrete is secured.

" Pipes made by the ordinary ramming processes are honeycombed with air-holes, and sweat through the concrete freely under very low pressure.

" 2. In the finely finished interior surface of the pipe, which offers the least possible resistance to the flow of liquids. The skin is secured automatically in the process of casting the pipe without any recourse to hand dressing with cement mortar, such as is always required for pipes made by other processes."

The usual forms of concrete sewer pipes are shown in figs. 99–102.

Before the general use of concrete sewer pipes, Mr Baldwin Latham, in his *Sanitary Engineering*, speaks favourably of them. He says : " They stand not only the effects of a severe climate, but the chemical action of the sewage, and are produced at a considerably less cost than a brick sewer or a pipe sewer of equal calibre. Moreover, they show an extraordinary amount of endurance, and remain perfect after severe frost, when brickwork often fails. . . . The pipes improve materially by age. . . . Cement pipes are perfectly water-tight, and are by no means so brittle as ordinary earthenware pipes. A blow that would shiver in pieces an ordinary earthenware pipe would simply drive a hole in a silicated concrete pipe. A concrete pipe is capable of withstanding the jars arising from heavy traffic over the streets . . . which is a quality of no small advantage, as the author (Mr Latham) has found that in some districts earthenware pipes have been found to split in a singular fashion, the cause of failure being due to the constant tremor of heavy traffic in the streets."

Another distinct advantage in concrete sewer pipes is that, having no sockets, they are easily shifted about the works by simply rolling them. This is an important consideration when the pipes are of large diameter. Again, a simple wash of cement suffices to make a tight joint, and ensures a very smooth bore.

Since the first edition of this book was published considerable advance has been made in the manufacture of centrifugally cast concrete pipes which are likely to supersede those made by the methods previously described.

Brick Sewers—Materials.—Great attention should be paid to the selection of good bricks for brick-built sewers, as they are subject to a wide variety of destructive forces. Bricks which are very absorbent are not at all suited to sewer work, for the same reasons as porous pipes, except perhaps gault bricks, which, while absorptive, have been found very suitable for this purpose. Perforated bricks should not be used, or any underburnt bricks. Porous bricks are liable to damage by frost, and this is an important point in sewer work. Samples of bricks should be tested as follows :—

The brick should be suspended by string in a boiling solution of sulphate of soda (which was previously prepared cold) for 30 minutes. Then, having freed the liquid from sediment, suspend the brick over it when placed in a flat vessel. Efflorescence will appear on the specimen, and it must be dipped in the solution two or three times a day for a week. At the end of that time, if the earthy sediment in the solution is collected and weighed, it will indicate the effect to be expected from frost on the same sample. This test may be applied to stone, mortar, or cement If no loss of weight results, and the brick in other respects is found to stand the test, it may safely be used for sewer work. Very soft bricks must not be used for sewers on account of the wear they are subjected to. The invert of a sewer is subject to the friction of such solid matter as the liquid moves along with it, and the use of invert blocks or Stafford bricks is desirable in good work. Glazed bricks are sometimes used. It very often happens that when sewer work is carried out in any particular district that there is a local brickfield. It will, of course, be cheaper to use these bricks, and the ratepayers expect the materials to be procured locally. They will probably be quite good for use on the arch and sides of the sewer, while if Stafford bricks and invert blocks are used for the invert a reliable sewer will result at a moderate cost. As a rule, picked stock bricks are less absorbent than gault bricks, and will bear an equal amount of compression. Stock bricks will compress in the hydraulic press to about half the original thickness before failure.

The use of ordinary shaped bricks is not to be advised for small brick sewers, owing to the wide joints which will be left at the back. Specially shaped bricks, except in very large quantities, are, of course, expensive, which makes concrete a favourite material for small built sewers. On the other hand, ordinary bricks may be used if sections of the sewer are built up or cast in blocks. To do this wooden moulds are made, which consist of long troughs, the bottoms of which are made to the true curves of the sewer. The sides are hinged and kept at the proper radius by ties, as shown in fig. 98A. The blocks are made in lengths of about 1½ or 2 bricks. The bricks are laid in the trough, which, when full, has cement grout poured in to fill all the interstices; when it has set, the block is removed and placed in position in the sewer. They are also used in bad ground; there is one disadvantage, however, and that is, the inferior bond to ordinary brickwork. Plenty of good cement mortar should be used in sewers to make them water-tight, and every crevice should be filled up and struck with the point of a trowel. The internal joints should not be greater than ¼ in. thick. The arches should be turned upon centres of the proper radius.

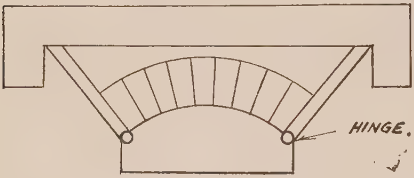

FIG. 98A.

No attempt need be made to effect adhesion between bricks and the jointing material in sewers. With the hard bricks used for the invert the adhesion in any case will be bad; but as the principal strains upon a sewer, by which it would fail, are external, and not internal, this does not have any serious consequences. In any ordinary cutting the superincumbent load is always far greater than the internal pressure; consequently there is no tendency for the work to be drawn asunder by tensile strains; on the other hand, with good cement mortar, there is sufficient adhesion to maintain the shape and solidity of the work and render it water-tight. The cement mortar will also stand quite as much compression as the best of bricks.

The lower part of built sewers is often constructed of specially hard bricks, known as "Stafford blue bricks." They are made from clays and marls found in the county, which contain about 7–10 per cent. of oxide of iron. They are burned at a high temperature, which causes the peroxide (red) to be converted to protoxide (black) of iron, which gives them their characteristic blue-black colour. They are very suitable to all classes of sewerage work. A special variety comes from Tipton. Blue bricks are usually the same sizes as ordinary bricks, but they only absorb about 2½ per cent. of water, and weigh about 9½ lb. each.

Samples of Stafford bricks used should always be tested, because there are many imitations now on the market which have none of the qualities of the genuine article. They are either merely coloured on the outside with a surface wash of iron, or have iron oxide mixed with ordinary clay.

Brick Sewers—Construction.—The Romans found that an arched sewer was stronger than one covered with a flagstone, but they continued to retain the flat invert. Now any hollow channel embedded in the subsoil is liable to be pressed upon and against by the weight and bulk of the surrounding solid materials, and the form of channel must therefore be able to resist effectually this pressure from without. The curved surface of an arch is stronger than a flat surface because the pressure on it is distributed to all the surrounding points on its surface, and their combined resistance is thus brought into action against this external force. But the pressure upon all parts of a sewer is not uniform. Hence the circle is not quite the best form of sewer in this direction. The top of it will be subject to the entire weight of the superincumbent earth *minus* friction, which prevents the filling from moving freely downwards. Again, the soil will set up pressure on the sides of the sewer with a force which will vary in inverse proportion to the tenacity of the material, while the bottom of the sewer will have no other pressure to meet except the reaction of its own weight and its superincumbent load. Of all these, the vertical pressure from above is the greatest; hence it appears that the elliptical form with the major axis

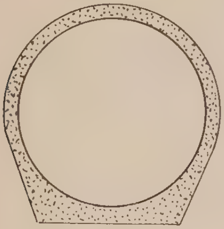
FIG. 99.

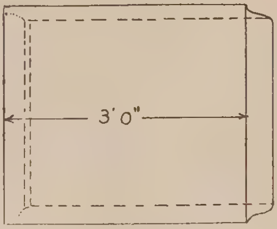

FIG. 100.

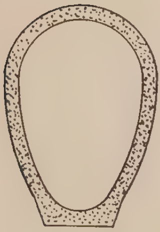
FIG. 101.

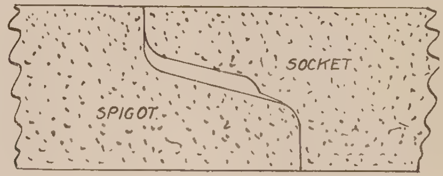

FIG. 102.—Detail of Joint.

TABLE XVIII.—TESTS OF SEWER BRICKS.

	A.	B.	C.	D.
Stafford bricks. Dressed blue	40·03	15·5	114·0	2·803
Stafford bricks. Pressed ,,	39·8	21·5	73·0	1·861
Stafford bricks. Common ,,	41·1	13·0	39·0	0·954
Stafford bricks. Bastard	41·2	27·0	41·5	1·006
And in reference to ordinary bricks suitable for sewers—				
Common red	38·7	9·5	57·0	0·96
Machine-made red	40·9	23	33·0	0·791
Common stock	36·2	10	128·0	3·558

A = area exposed to crushing in sq. in.
B = average weight in tons per sq. in. under which brick cracked.
C = ,, ,, required to crush brick (total).
D = ,, ,, ,, ,, (per sq. in.).

vertical would satisfy this condition by providing the greatest resistance in a vertical direction; but in order to satisfy hydraulic conditions, the egg-shaped sewer has been gradually evolved. For small pipe sewers, where economy of construction is not aimed at, it possesses little advantage, although egg-shaped pipe sewers are made. In the construction of circular or "barrel sewers," as they are sometimes called, only skilled men accustomed to the work should be employed. Where the ground is good, the excavation is finished as in fig. 103. The ordinary excavation proceeds in the manner described in the previous chapter; but when the springing level of the sewer is reached, a frame similar to that shown in the figure is used as a guide for the excavator.

The frame shown is the finished guide for the bricklayer. The excavator uses a rougher frame. Sometimes two others are used of varying size and accuracy, the first being about 4 in. smaller than the proposed finished profile. The trench must be very carefully pared to the correct profile.

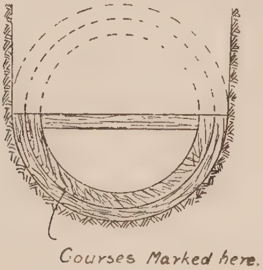

FIG. 103.

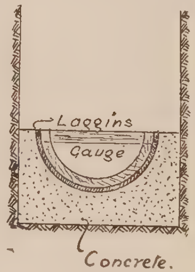

FIG. 104.

On the finished frame the exact position of each brick is marked by notches. It is by no means usual, however, to find the subsoil in such a state as to allow of this method of construction; and when loose, a concrete foundation is quite necessary for a barrel sewer. It is put in the full width of the trench by means of a gauge, as shown in fig. 104, the concrete being carefully put in equally on each side. It may here be said that in any trench, when the bottom is found by the engineer to have been excavated below the full depth, it must be refilled up to the required level by Portland cement concrete only, and not by excavated earth under any circumstances. A clause to this effect is most essential in any specification.

An ordinary barrel sewer of brickwork or concrete does not present any special difficulties to the engineer. The centering employed is simple; it is substantially the same as for any small arch. The thickness of brickwork depends on the depth and the size of the sewer. A rule to ascertain it is as follows, which will also apply to an egg-shaped sewer:—

$$\left.\begin{array}{l}\text{Let } R = \text{radius} \\ \quad D = \text{total depth of excavation} \\ \quad T = \text{thickness}\end{array}\right\} \text{all in feet.}$$

Then

$$T = \frac{RD}{50}.$$

For instance, in a 7-ft. barrel sewer 20 ft. deep, $T = \frac{3{\cdot}5 \times 20}{50} = \frac{70}{50} = 1{\cdot}4$ ft.

Probably four rings of brickwork would be employed$=4\times4{\cdot}5=18$ in.$=1{\cdot}5$ ft. For an ordinary concrete sewer this could be increased $\frac{1}{4}$ using a $4\frac{1}{2}$–1 mixture. When the foundation is too unstable to withstand the weight of a sewer, special methods are employed. For a pipe sewer a system of piles and rolled steel joists is shown in fig. 105, the whole sewer being surrounded with concrete. The piles would be driven to a solid foundation until they did not sink more than $\frac{1}{5}$ of an inch for every 120,000 ft.-lb. applied. The same method would apply to a brick sewer. If the excavation was not deep it would probably be cheaper to form a raft foundation of reinforced concrete, using meshing of considerable width, but the amount of excavation in a deep trench would be very excessive. A sewer in yielding ground, of course, wants very careful consideration. In many situations the site will vary considerably in solidity, some portions of the ground being capable of bearing a much greater load than others. The result is, the sewer settles unequally, and has induced bending moments in its body, which will cause it to fail and become utterly useless. The writer has taken up some pipe sewers which have completely collapsed, concrete bed and all, from this cause alone. Knowing, then, the load per foot-run on the bed, the depth of the bed, and its proposed width, the makers of any particular form of reinforcement used will suggest a suitable section for the job.

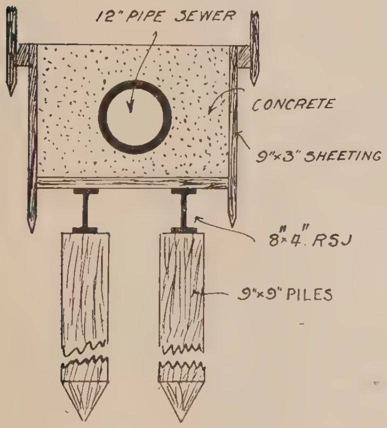

Fig. 105.

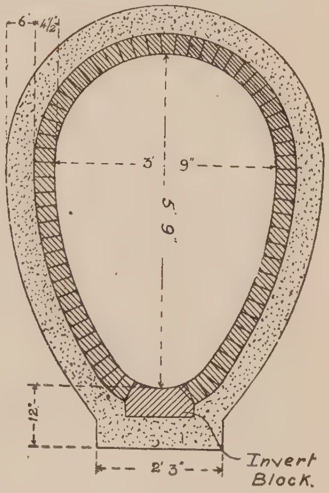

Fig. 106.—Egg-shaped Sewer.

The egg-shaped sewer is constructed in a similar way to the barrel form, viz. the lower half is suitably moulded and an arch turned over the same. A form much employed in good ground is that shown in fig. 106, a special block being used for the invert. Various forms of these blocks are now made by the fireclay makers. Their use is advocated, as, when set to the correct gradient, the accuracy of the remainder of the work is ensured. Blue bricks may well be used up to the springing line. Another detail is shown in figs. 107, 108, and 109, special attention being directed to the junction blocks.

When the sewer is made with 4½ in. brickwork it should be constructed as in fig. 110, having a top hood of concrete. When the ground is wet. subsoil water has to be dealt with and provision made for its removal. This may be done, as shown in fig. 111, by placing field drains in a bed of washed cinders or large gravel, and leading them to suitable outfalls. This may also be done in the case of an ordinary pipe or barrel sewer. In the case of egg-shaped sewers, the invert blocks may be made to do the same duty.

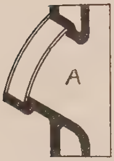

Fig. 107.

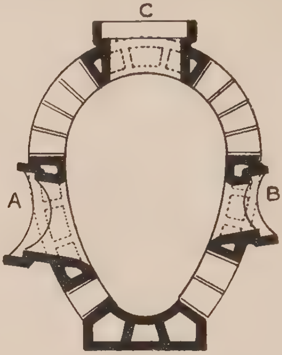

Fig. 108.

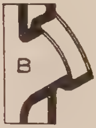

Fig. 109.

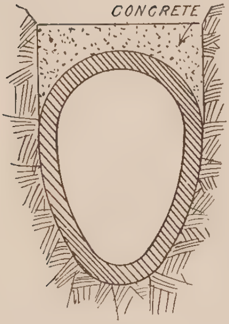

Fig. 110.

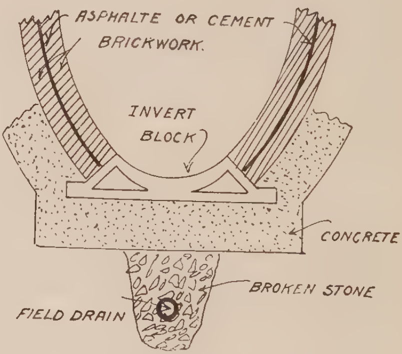

Fig. 111.

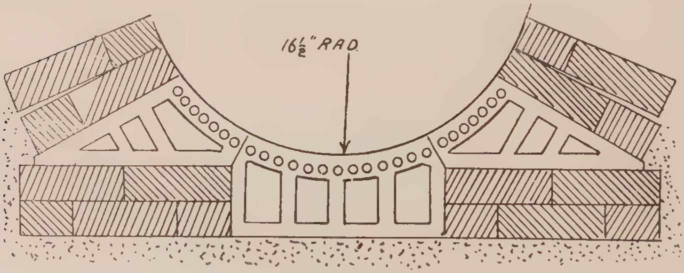

Fig. 112.

Figs. 112–115 show good forms, as used in London.

The particular ones in question are made by Thomas Wragg & Co. of Swadlincote, who are well known in the sanitary pipe trade. In referring to them they state:

"The practice of connecting pipe drains with brick sewers by building-in the pipes, which, in whatever manner and however carefully it may be attempted to be done, has long been recognised by engineers to be most unsatisfactory, led some thirty years ago, more especially in the vicinity of London, to the introduction of junction blocks of stoneware. The primitive form then given them was a great improvement on the objectionable practice of building-in the pipes, but little or no improvement was effected in the form of these blocks until some ten years later, on the issue of drawings for an improved form of block for Continental works, under the direction of Mr Gordon.

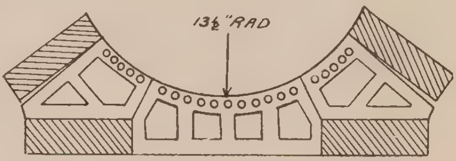

Fig. 113.

"Still further improvements have now been effected in these blocks, as adopted and required by the building regulations to be used at Leicester, and we feel satisfied, as the manufacturers of them, that they only require to be more widely known to become more generally adopted.

"They are made, as will be seen by reference to the previous diagram, fig. 108, to the exact contour of the sewer in section, and so as to admit of the pipe to be joined to the sewer being connected at an angle of 60° with the axis of the sewer in the direction of the flow, thus ensuring every drain connection being joined to the sewers in the proper direction.

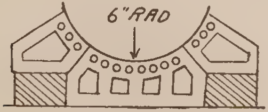

Fig. 114.

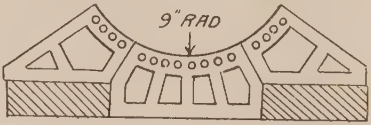

Fig. 115.

Invert Blocks for Egg-Shaped Sewers.

"The drawing shows an egg-shaped sewer of 4½-in. brickwork only, but the blocks are made on the same principle for circular and for any size of sewer and thickness of brickwork that may be required.

"The junction block C (fig. 108) shown on the crown of the sewer will be found most useful in connection with the ventilation of sewers as a starting-point for vertical shafts, which it is recognised by engineers should be started from the highest part of the sewers, so as to admit of the escape of the air under compression when the sewers are filling with water.

"These blocks will be found especially valuable where connections have to be made with sewers at points where no kind of provision has been made for the reception of a side drain. The common practice of breaking into the sewer and inserting a pipe has, in the opinion of competent authorities, been productive of as much mischief, and as many sewer and drain stoppages, as almost all other causes put together. The pipes are frequently so badly connected as to project into and half across the interior of a sewer, and are connected not infrequently into the haunch of the arch in such a manner that a collapse of the sewer is, as a consequence, no uncommon occurrence.

"A and B (in fig. 108) represent respectively 9-in. and 6-in. junction blocks, the one being a right-handed and the other a left-handed block. In ordering blocks it is therefore essential to say whether right-handed or left-handed blocks are required; and in order that there may be no misunderstanding in reference thereto, it must be understood that in speaking of right or left hand you are supposed to be looking in the direction of the flow of sewage."

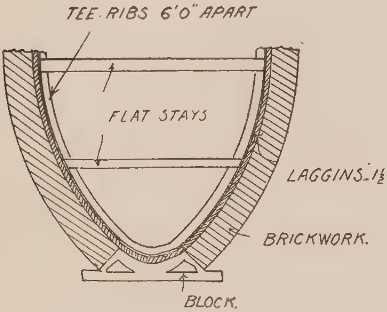

FIG. 116.

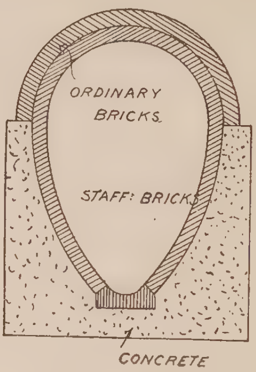

FIG. 117.

When the blocks are set the centering is erected thereon. A suitable form is that shown in fig. 116. It consists of ribs of tee iron about 6 ft. apart, to which are attached lagging of 6 in.×1½ in. timber, kept apart by stays of flat iron. The system is distinctly superior to the old wooden centre for a concrete sewer, or a concrete core for a brick one.

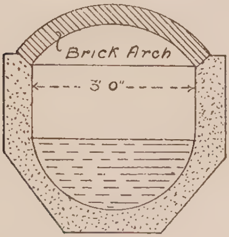

FIG. 118.

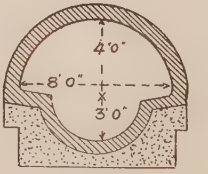

FIG. 119.

Another variety of egg-shaped sewer is shown in fig. 117, while sometimes they are made of concrete, lined with special tiles, which Messrs Doulton make for the purpose.

Two special forms of sewers are shown in figs. 118 and 119.

Collapsible Centering.—"Considerable saving may be effected by the use of the Blaw system of collapsible steel centering shown in fig. 120.

"Referring to the method of constructing a 3-ft. circular sewer, it was formed of two rings of brickwork and surrounded with concrete. The culvert is included in a contract for certain bridges, etc., let by the London and North-Eastern Railway Company to Mr T. Telford Gibb, contractor, of Westminster.

"Steel centres in segments of 5 ft. in length were used for forming the concrete invert 4 ft. 6 in. in diameter, and for the top half of the brickwork centres, 3 ft. in diameter; the centering was set in lengths of 50 ft. at a time.

"The excavation being down to the full depth, 9 in. of concrete was deposited in the trench, bringing it up to the level of the bottom of the invert; then the 4 ft. 6 in. centres were placed on the top of this, being held in position and prevented from rising by timber placed at intervals over the top end wedged against the sides of the trench: the concrete was then rammed in round the centres, and allowed to set, and the centres then removed. The brickwork for the bottom half of the culvert was then built, and on the top of this the 3-ft. diameter centres were placed and the upper half of the culvert brickwork built on these. Then the remaining concrete was formed on the top of the brickwork.

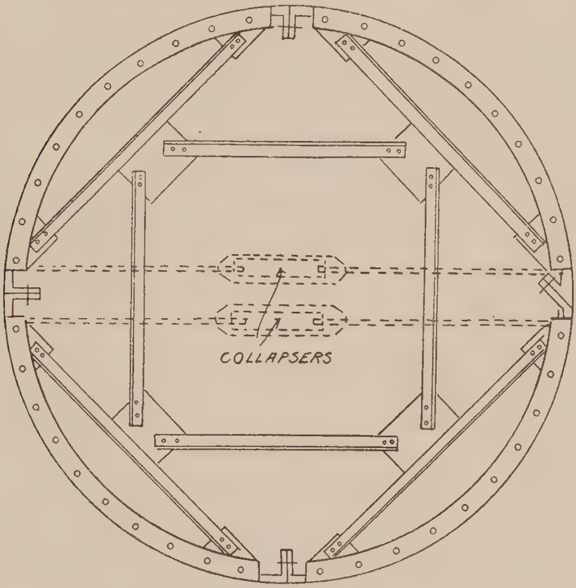

Fig. 120.

"The steel centres were withdrawn by tightening the union nuts, which withdrew the centres from the formed brickwork or concrete, and union nuts were then loosened, and the rods and union nuts removed, and the centres were drawn forward, then the rods were replaced and tightened up, and the centres were then ready for further use.

"The centres made a very smooth and perfect surface and form on the concrete and joints of the brickwork, and, excepting brushing, have not needed to be cleaned or repaired in any way."[1]

Concrete for Sewers.—Most sewers, as well as all other constructive works, can be made of concrete, and it is necessary here to investigate the essential properties of this most important material.

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[1] Catalogue of the Blaw Collapsible Steel Centering Co.

The ways of specifying cement are various, each engineer having his own favourite mode of testing and specifying. A good general specification, which will usually ensure a good, even quality of cement being delivered by the manufacturers, is as follows :—[1]

"The cement shall be of the very best quality, and subject in every respect to the approval of the surveyor.

"It shall be packed in strong, perfectly sound sacks. Any torn or hard sacks will not be accepted.

"The cement shall be subject to the following tests :—

"It shall be very finely ground, so that not more than 5 per cent. by weight shall be stopped by a sieve with 76 by 76 meshes per square inch ; it shall have a specific gravity of not less than 3·1. Samples made into briquettes and immersed in water twenty-four hours after being made, and remaining immersed until tested, shall have an average tensile strain, seven days after being made, of not less than 350 lb. to the square inch ; and twenty-eight days after being made, the average tensile strain of the briquettes then tested shall be at least 20 per cent. more than the average of the seven days' test. The cement shall not set in less than one hour, and shall be considered set as soon as no impression can be made on it with the thumb nail. Other tests may be applied at the surveyor's discretion.

"Pats of cement made with water, and allowed to set for five hours in a damp atmosphere, at a temperature of 100° F., and afterwards immersed for nineteen hours in water at the same temperature, shall show no deterioration.

"If the cement does not come up to these tests, it shall be removed from the store by the contractor, and at his own expense, within fourteen days of written notice to that effect being given to him by the surveyor.

"Samples for testing to be taken from the consignments, at will, by the surveyor or his representative, who shall have the tests made, the cost for doing which shall be defrayed by the contractor."

When the contract is a large one, the specification may be and is more exacting, but for general purposes in this country the above is all that can be desired. In manufacture, the proportions of clay and chalk or lime are very variable, and no standard proportions can be quoted.

The chief place of manufacture is the valley of the Thames and Medway, where the alluvial deposit seems to have special qualities. The brands are legion, and it would be impossible, for obvious reasons, to describe any one manufacturer's brand as being in any way superior to another.

The average proportions of cement may be taken—clay three volumes to one volume of chalk ; sometimes, however, the chalk may contain clay, and the mixture has to be modified accordingly. For testing quantities of cement on large contracts, Faija's machine is almost universally used.

Ordinary cement of the best quality is usually heavy ; and a heavy cement is a slow-setting cement, which for heavy work is desirable. It should be of a blue-grey colour, and show a compact dark fracture. The usual weight is 110 lb. to the bushel, and the amount of water required in mixing about 3 gallons per bushel. When brown, it shows that the proportions in manufacture were not properly gauged, and that an excess of clay was present; whereas if it is very blue, one may infer that it has been over-limed, and that it is liable to blow. A cement which will blow is not properly cool, viz. it is a "hot" cement. By plunging the bare arm full length into a bag of cement an experienced engineer or clerk of works can tell by the feel if the cement is "hot." The temperature should appear as near as possible the same as the arm if the quality is good.

---

[1] On important works British Standard specifications are now almost invariably used.

Too much lime in a cement unfits it for sewer work, owing to the chemical action of the sewage destroying the carbonate of lime. The liability to blow may be tested for by seeing if the cement cracks round the edges after immersion in water for a day or so. Also, if a bottle is filled with neat cement and the bottle cracks, that cement will be too hot; if, however, a shrinkage takes place it is underburnt. Some engineers use a hot cement in underpinning work, because, when the concrete is rammed well in, the expansion due to the hot cement causes the whole to consolidate very considerably.

Cement must always when stored be emptied out of the sacks and put on to a floor of wood 2 ft. 6 in. deep; in a dry weatherproof building this will cause it to increase in bulk. A cask of cement contains $3\frac{1}{2}$ bushels, while a sack contains 2 bushels=2 cwt.; and for mixing 6–1 concrete a box 5 ft. × 3 ft. × 1 ft. is used to one bag of cement.

Roman cement, also called *Medina cement*, used for jointing sewer pipes, is a natural cement made from the septaria nodules found in Hampshire, the Isle of Wight, and elsewhere. These are burnt, with the result that they lose $\frac{1}{3}$ of their weight; on grinding, however, they increase again by $\frac{1}{11}$. It is generally used neat, principally for sewer work and for work in which very quick setting is required. It loses strength if mixed with sand, and also has the disadvantage of disintegrating with age. The tensile strength at the end of seven days is about 90 lb. per sq. in. It should not weigh more than 75 lb. per bushel. If so, it may be concluded that it is either stale or overburnt, two undesirable qualities. The colour is a rich brown, similar in many respects to cocoa, but not quite so dark.

In concrete there are two essential parts, the *aggregate* and the *matrix* or binding material. The aggregate is best made from porous material, broken up into small angular fragments. Slag from iron furnaces, if not too vitreous, is very suitable. When large stones are inserted during the laying of the concrete they are termed "displacers." They must always be wetted before setting, and must never touch one another, but be completely surrounded with the concrete. For concrete flags,[1] shingle should be used as aggregate and very little sand added. It must be well washed, like sand, especially if from a sea-beach, to rid it of any salt, which, being hygroscopic (that is, possessing an affinity for moisture), will cause dampness in the structure.

The proportions of concrete vary. The sand should, if possible, be clean, sharp, well-washed river sand, free from loam or earthy matter. Pit sand is not so good, although extensively used, while sea sand is best avoided altogether, for the reasons stated above. When the concrete is liable to exposure to heat, a small proportion of gypsum may with advantage be added. Concrete made with hydraulic lime is termed *Béton*.

Ferro-Concrete Sewers.—By ferro-concrete is meant concrete and steel intimately blended, so to speak, whereby the tensional stresses are borne by the steel and the compressive stresses by the concrete. The whole subject would form a treatise in itself; it is not proposed to discuss the question here, but the reader is referred to any standard work, and to the treatment of the subject in the author's *Manual of Civil Engineering Practice*. Brick and plain concrete sewers are not suited to working under hydraulic pressure, or "head," as it is called. A circular sewer of this kind must not run more than ½ full, and an egg-shaped sewer ⅔ full, while fireclay and stoneware pipes are not suited to working under a head of more than 3 ft., and then not particularly so. Sewers—gravitational sewers—do not, of course, work under pressure, except under unusual circumstances; but in large schemes some of the sewage may have to be raised by methods to be described. This in the past necessitated the use of cast-iron or riveted steel sewers, always liable to corrosion in a greater or less degree, but the introduction of ferro-concrete supplies an alternative method of overcoming the difficulty. Considering any strip of a sewer under pressure equal to B in fig. 121, the internal diameter of the sewer being D in the same units; then if P=the unit pressure on the sides and S=safe unit stress in the steel reinforcement, the area of steel required=A.

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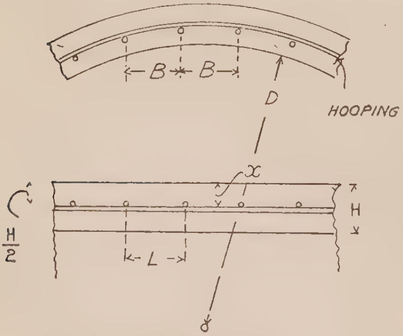
[1] Used for covering manholes and chambers.

$$A=\frac{PDB}{S},$$

P being found from the head of water under which the sewer works, and equal to

$$0{\cdot}213\ H.$$



FIGS. 121 and 122.

A sewer, then, that is constructed on the above assumptions will have a concrete shell much thinner than that of an ordinary concrete one without reinforcement, 6 in. being about usual. This applies to the use of longitudinal reinforcing bars, the area being ascertained by considering a portion of the shell between the hoopings which bind the bars together as a beam fixed at the ends. The hooping is shown in fig. 121, B being about 6 in. Bearing this in mind, a formula can be evolved for ascertaining the value of the percentages of reinforcement in relation to the effective thickness beyond the longitudinal bars. Let A_1=the area of these bars, and L, H, and x as in fig. 122. Then considering the effective thickness *inside* the reinforcement P, the percentage referred to equals

$$\frac{A_1}{BH(1-x)},$$

and if p=the same quantity when the effective thickness *outside* the longitudinals is considered,

$$p=\frac{A_1}{BHx}.$$

Values of P and p will then be found by trial and error till suitable ones are obtained. But a sewer of this kind may not always be required to withstand an internal pressure, but, in common with other sewers, it may have to withstand external pressures. The pipe then becomes a column under compressive stress, with a total load=W.

If the superincumbent earth then sets up a pressure=P on the external diameter=D, then

$$W=\frac{PD}{2}.$$

Again, let M=the ratio of the coefficients of elasticity of concrete and steel, usually taken at 15,

$$c=\text{a constant}=500.$$

A_2=sectional area of hooping in any length of pipe=L. Then if a=LH,

$$\frac{PD}{2}=C[a+(M-1)A_2].$$

Again, knowing H, as

$$A_2=pLH,$$

$$\therefore \quad p=\frac{A_2}{LH}$$

$$\therefore \quad \frac{PD}{2}=500LH(1+14p),$$

from which H can be found. Longitudinal bars, in conjunction with hooping, have been found useful in sewer construction. The writer, however, is inclined to favour the use of mesh reinforcement in this direction in preference to other methods.

On account of its rigid net-like formation, giving a series of continuous helical bands of reinforcement, diamond mesh expanded steel forms one of the best possible reinforcements for strengthening concrete in pipes.

The sheets can be cambered either long way or short way of mesh to suit any requirements. The diagonals of the meshes should run one with, and the other at right angles to, the periphery of the pipe.

The reinforcement should not only be laid, but it should also be fixed in position, so that there may be no possibility of its losing its correct position ; and it is advisable to clip or wire the sheets together at overlapped joints, and for pressure pipes to allow an overlap of two meshes. Not less metal than the amount provided as overlap should be left protruding beyond each deposit of concrete, to form a bond between that already laid and the fresh material.

A carefully built sewer may be found to "sweat" a little at first, or even to crack slightly, owing to shrinkage or other causes, but it invariably "takes up" with sediment and lime deposits flowing through it, and thus in a short time becomes perfectly water-tight.

With particular regard to pressure pipes, the concrete forming the main shell should not be depended upon for impermeability, for experience has shown that tamping seams are to be feared, no matter how carefully fresh material may be added to that which has already been laid.

For pressures up to 50 ft., a $\frac{3}{4}$-in. facing of cement and sand 1 to 2, laid in one body on the centering immediately before the concrete, has proved effective. But for greater pressures, say up to 100-ft. head, the facing should be laminated or put on in coats, the first coat not less than $\frac{1}{2}$ in. of cement and sand 1 to 2; the second of about $\frac{1}{4}$ in., 1 to 1, trowelled to a hard polished surface, and a final wash of thick grout.

Generally speaking, the thickness of the concrete should in no place be less than one-twelfth of the greatest internal diameter of the pipe, with an allowance of 1 in. for cover to the reinforcement, whilst the steel should be designed to resist the whole of the tensile stress.

For expanded steel, which has a safe tensile stress of 8 tons per square inch of sectional area,

P=the pressure in lb. per square inch,
r=the internal radius in inches, then the weight of expanded steel per square foot

$$=\frac{Pr}{440},$$

while its area at each side of the pipe per longitudinal foot, where f=the safe tensile stress in the expanded steel in lb.

$$=12\frac{Pr}{f}.$$

Typical examples of reinforced concrete sewers are shown in figs. 123–126.

Composition of Concrete.—Seeing the important part reinforced concrete now plays in all works connected with main-drainage and sewage-disposal works, it will be well to consider this material more closely, because the mixing and ramming of the mixture in place is the most important part of the whole work. It must be very carefully done by experienced workmen.

When ballast is used it should be well washed and quite free from loam. It should contain a fair percentage of sand. Broken limestone makes a very good aggregate. Sandstone is not to be recommended. Diorite, a crystalline rock, is excellent, as also is crushed granite. Broken brick can be well recommended. It must, however, be very well washed before use, and used wet. Blast-furnace slag will be found satisfactory if it is selected with great care. It must, however, be porous, and not too glassy, and absolutely free from sulphur. The presence of sulphur in any aggregate must be entirely eliminated; this can only be done by repeated washings and weathering.

Sand.—The sand used in this particular work requires very careful selection. In the first place, it must be a happy medium between dust and coarse sand. It must be clean.

Sharp sand is the best in practice, because it is usually of a siliceous nature. Test mixtures of the concrete can be made in the office, proceeding as follows:—

Procure a piece of iron tube and make a mixture similar to that which it is proposed to use. Very carefully note down its composition, then mix it and ram it into the piece of tube, which was previously sealed at one end by means of a screwed cap. Carefully measure its height in the tube when fully rammed. Then clean out the tube again and make a fresh mixture, varying the *proportions* of sand and broken stone, but still having the same total weight of the two combined. If less or more, it will be a guide to the future adopted proportions. Again note the height of the sample when rammed. Repeat this process a few times. The *lowest* height proves the *best* mixture, but they must be very accurately proportioned if they are to be of any practical value. The following proportions for concrete have, according to the class of work, been found to answer well in practice:—

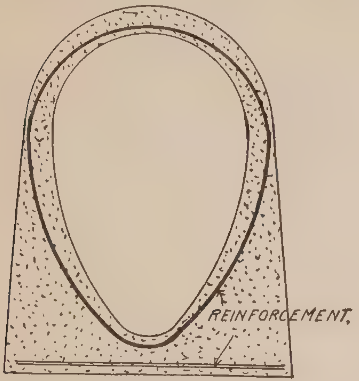


Fig. 123.

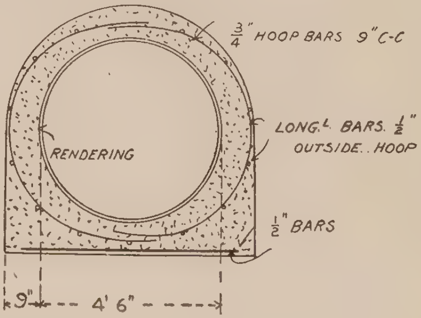

$\frac{3}{4}$" HOOP BARS 9" C-C
LONG.L BARS. $\frac{1}{2}$" OUTSIDE. HOOP
RENDERING
$\frac{1}{2}$" BARS
9"
4' 6"

Fig. 124.

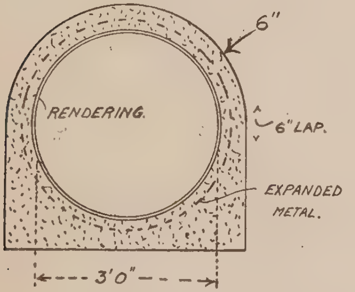


Fig. 125.

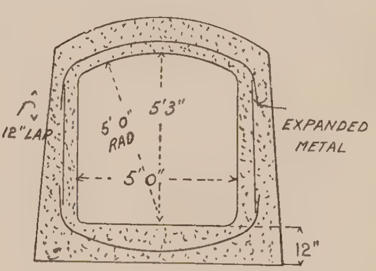


Fig. 126.

Table XIX.

	Cement.	Sand.	Aggregate.
Reinforced concrete . . .	1	2·0	4
Arches, ordinary walls, and stairs .	1	2·5	5
Heavy walls, piers, etc. . . .	1	3·0	6
Large masses, such as harbour works	1	4·0	8

All water used should be carefully selected ; it must be clean, free from acid and strong alkalies. It must not have much lime present, and must be free from organic impurities. The average quantity required would be from 21–24 gallons per cubic yard of dry mixture.

Concrete should not be tipped from a height, as might be considered an advantage, nor should it be applied in frosty weather. If, however, this would be quite unavoidable, as in the case of cold climates, 1 per cent. of salt may be added with advantage, or a warm mixture used. The average composition of a cubic yard of concrete would be as follows, according to the proportions used :—

TABLE XX.

Proportion.	Portland Cement in lb.	Cubic yard of Sand.	Cubic yard of Ballast or Stone.
1–2–4	590	0·44	0·88
1–2½–5	485	0·45	0·91
1–3–6	414	0·46	0·93
1–4–8	320	0·48	0·96

Regarding forms for concrete work, any cheap wood will do. The wood should *not* be seasoned. The forms must be well coated with soft soap or oil before use to prevent them sticking. In case, however, the particular work has to be afterwards plastered, this will not do ; in such a case they must *only* be wetted. Cement mortar may have the proportions of 1–2, 1–3, or 1–4, according to circumstances. The addition of ½ to 1 per cent. of lime putty is a distinct advantage, especially for plastering work, as it will tend to make the mortar flow easily.

All steel used in concrete steelwork must be surrounded by at *least* 1–2 in. of concrete, according to the size of the structure. The whole success of concrete steelwork, apart from the scientific design, depends on proper mixing of the concrete. This may be done by hand, but when it is, it wants very careful doing by willing workmen. The machine mixer is a much more satisfactory appliance, and is now used on all contracts of any magnitude. They may be hand or power driven ; of the rotary type, Taylor's or Ransome's are perhaps the best known as giving satisfactory results. Gravel mixers are also in vogue. The principle is, that by means of baffle-plates the mixture thrown in at the top descends by a devious path from one side of the machine to the other, water in suitable quantities being added meanwhile. A gain of about 11 per cent. on machine mixing can be relied upon.

Regarding the strength of concrete in tension, it may be taken anywhere between 200 and 300 lb. per square inch, principally according to age. For instance, it has been found by experiment that a 1–2–4 mixture will give the following average results :—

26 days old . . .	280	tensile strength, lb. per sq. in.
28 ,, ,, . . .	360	
33 ,, ,, . . .	305	
35 ,, ,, . . .	300	

Special Forms of Sewers.—Besides the examples given there are special forms of sewer construction, principally in connection with taking pipes over and under rivers and other natural depressions, and for outlets into tidal and other waters. A special chapter will be devoted to the consideration of the first named, remarks here being confined to outfall sewers. It is the prevalent practice in seaboard towns to discharge the sewage into the sea by means of specially constructed outfall sewers, often of the "tank" type already referred to. This often entails a large outlay of money, especially in tidal waters, chiefly because of the large amount of rise and fall, necessitating long outfalls, and also the fact that the work can only be done at low water, and is very often damaged by storms before completion. The proper point for the actual outfall is a few feet below low water of the ordinary spring tides. Then, again, the currents, as before mentioned, require very careful consideration. Where very high tides and a heavy rainfall are at all likely to be encountered at the same time, and the scheme is a gravitation one, some form of tank sewer is absolutely essential, because in a town which has a low-lying district contiguous to the sea, with steeply rising ground at the back, such conditions, unless amply provided for, will be sure to result in flooding of yards and basements. Whilst this can be avoided by special traps, the sewerage should be designed so as to eliminate these unsatisfactory appliances.

The actual outfall sewer is a piece of work which always gives rise to difficulty to the engineer, the work usually being very troublesome, and it is seldom that two cases will occur alike; the shifting nature of the beach and other things will always crop up and alter circumstances, so that no hard and fast designs can be laid down. Cast-iron and steel pipes laid along the shore, with joints of the ball and socket type, have been tried with more or less success. This system makes the pipe practically flexible from end to end. Such an expedient was resorted to in the Waterford main drainage outfall into the river Suir. Of the flexible joint there are many types on the market, each claiming, of course, special advantages.

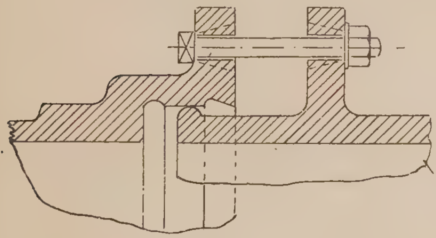


Fig. 127.

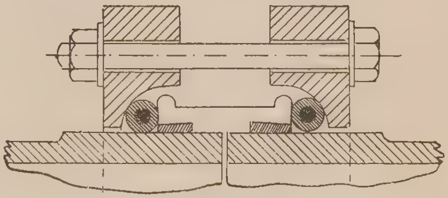


Fig. 128.

That made by the Stanton Ironworks is illustrated in fig. 127, while fig. 128 shows Humphrey's patent coupling; fig. 129 is that made by Messrs MacLaren & Co., Glasgow. Perhaps the more usual practice is to fix the pipes to piles or concrete blocks, or even building the outfall of masonry or concrete entirely. When piles are used, however, they require to be specially strong. The use of timber piles in tidal waters is far from satisfactory unless they are of greenheart, which is very expensive and seldom used. Steel has been tried with more or less success. Reinforced concrete proves eminently adaptable to such cases, and a system known as the Simplex is worth noting.

The essential principle of the system lies in the driving of a tube closed at the lower end, either by a loose point or a pair of hinged jaws, which open when the tube is being pulled up and permit concrete to be passed through, filling up the space left by the tube simultaneously with its withdrawal. The tube or *forme*, as it has been named, is of ¾-in. or ⅞-in. lap-welded steel, generally 16 in. in diameter, and from 30 ft. to 40 ft. long, made up of two or three lengths, cross welded. The upper end is strengthened to withstand the impact of the hammer by a ⅞-in. riveted band 18 in. deep, and a narrower band ½ in. thick is riveted on the bottom, where it bears on the shoe.

Fig. 130 shows a drawing of the ordinary form of Simplex pile.

It is not necessarily reinforced, but where reinforcement is desirable it can easily be placed in these piles. Various types of reinforcement have been used, including rods wired together to form a cage, cylinders of expanded metal, or single bars, either round, square, or I-section. The reinforcement is usually placed in the tube before concreting, and if in the form of a cage, a special funnel is employed through which the concrete is poured, so as to fall down the middle of the cage without touching the horizontal wiring. The reinforcement of an ordinary concrete pile is necessary to enable the pile to be driven, but is of very little value in increasing its final carrying capacity. At the best, the difference in the coefficient of elasticity of the two materials only permits the steel to be calculated as carrying fourteen times as much as the same sectional area of concrete, while it costs from forty to fifty times as much. Clearly, therefore, the use of steel is uneconomical where, as in most ground, the piles are not subject to any stress but the direct load. The Simplex concrete pile can be placed without steel at all. Reinforcement against flexure under a central load is quite unnecessary in a pile which, having the support of the earth, cannot at all be regarded as a long column. The earth enables it to carry a load far in excess of what it could carry as a column, just as a needle, if embedded in a cork, can be driven through a penny—an experiment most of us have tried in our youthful days. If, however, there is any tendency for the ground to move and put a sheering

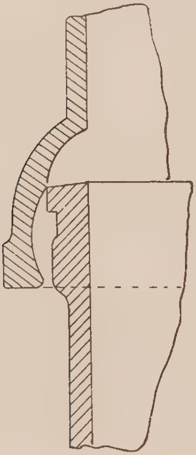


Fig. 129.

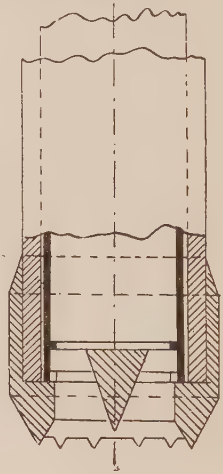


Fig. 130.

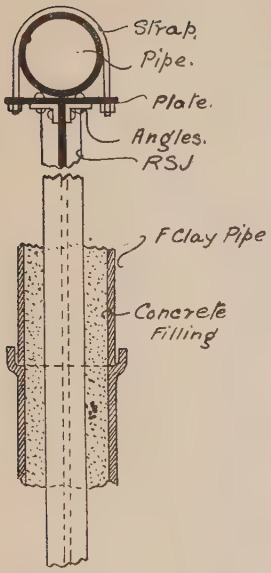


FIG. 131.

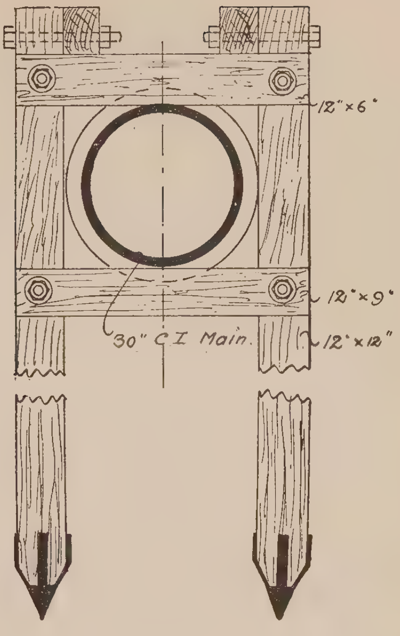


FIG. 132.

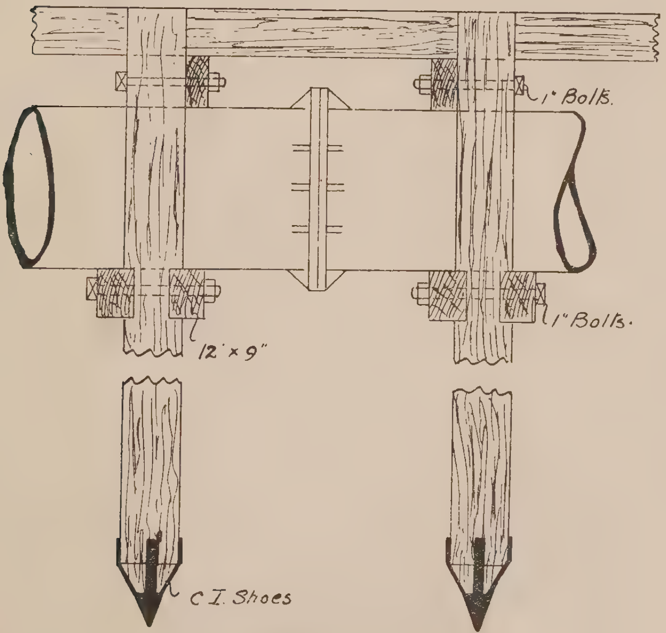


FIG. 133.

stress on the piles, reinforcement becomes necessary, and the Simplex pile can be reinforced as heavily as desirable. Another good system is that shown in fig. 131. It was adopted by the engineer to the Durham main drainage for carrying pipes along the riverside. Rolled steel joists were driven to a sound foundation, after which the soil was excavated to well below the river-bed, and the pile was finally encased in sewer pipes, into which concrete was well rammed. Another system is shown in figs. 132 and 133, in which an outfall sewer is carried on timber piles, the pipes being ordinary cast-iron flange pipes with turned faces. This kind of flange joint is the most suitable for the purpose. It is made with flat rubber rings between the flanges. Alternative systems are shown in figs. 133 A and B. In A the joint is made by a rubber or gutta-percha ring in the V groove, while in B the ring is in the recess shown.

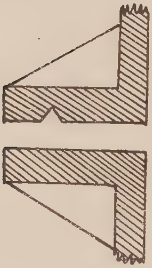


FIG. 133A.

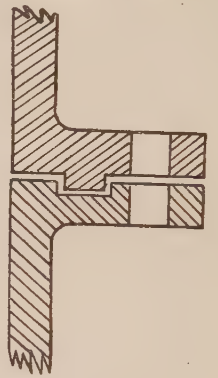


FIG. 133B.

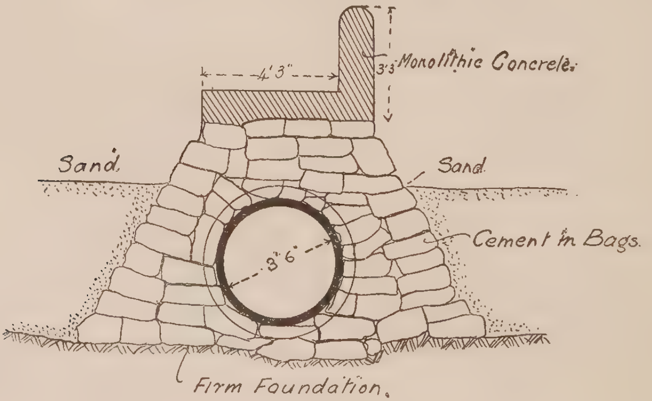


FIG. 134.

It might be considered by some that steel pipes would be best for this purpose, but they rapidly corrode in such exposed situations; and cast-iron pipes being considerably heavier, add to the stability of the work as a whole. Cast-iron pipes could also be placed as shown in fig. 134, which, provided with a firm foundation a few feet below beach-level, would make a very sound job. Such a system could also be employed in connection with a harbour breakwater under construction, but on no account should fireclay or stoneware pipes be used in this way, because settlement would be sure to fracture them. The writer had to alter the outfall of a town's sewerage for this very reason, 30-in. fireclay pipes having been laid in a concrete breakwater. Settlement cracked the pipes, and the sewage poured out into the harbour through the joints in the concrete blocks, and gave rise to such nuisance that the Urban District Council were threatened with legal proceedings. Pipe lines into rivers and tidal waters usually terminate in a suitable hinged flap valve of the form shown in figs. 135 and 136, well set in concrete, accurately balanced, with turned faces and bronze nuts and bolts.

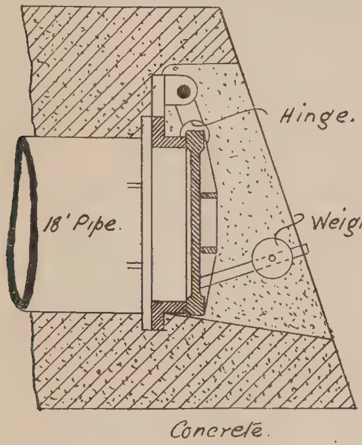


FIG. 135.—Section.

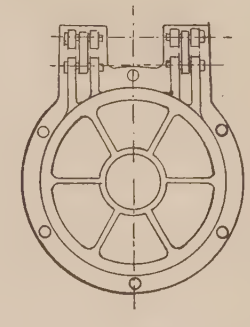


FIG. 136.—Elevation.

CHAPTER VI.

VENTILATION OF SEWERS.

Upon the question of sewer ventilation, which is a very much debated one, experts are often entirely at variance in their views upon salient points. The views of various parties will be dealt with and discussed ; but at the outset the writer desires to say that he is an advocate of thorough ventilation of sewers and house drains. It is obvious to all that, wherever there is the least chance of any stagnation of sewage taking place, the same changes occur in it as in the case of cesspools, and offensive gases are given forth in large quantity from the decomposing mass. These gases are of the same nature as those found in cesspools. In many towns no pretence whatsoever is made at ventilating the sewers, while in others it has been attempted to get rid of the foul gas by means of untrapped gully holes, which gave such offence that the trapped gully now universally used was resorted to. It is quite right to say that smooth pipe sewers, regularly flushed, are not likely to require as much ventilation as badly laid brick sewers, in which accumulation takes place and foul air is generated. In sewers without sufficient fall there is a liability to stagnation and deposit of silt. On the other hand, on steep gradients ventilation must be provided for, to prevent the ascent of sewer gases to higher localities. "In fact," says Mr D. K. Clarke, "as a principle of universal application, a system of sewers over an entire town should not be laid down without in the first instance providing as part of the scheme for the fullest and freest ventilation at all parts of the town, generally most necessary at the upper and higher levels."

It is well known that sewer gas is lighter than atmospheric air, and has a tendency towards upward flow. Again, the velocity of sewage water downwards is proportional to the gradient of the sewer. Hence a town with steep gradients requires the fullest ventilation, and such towns are the most difficult to ventilate efficiently. Sewer gas is a mixture of many gases, and its composition depends on the state of the sewage generating it. The most frequently found gases are:

1. Carbonic acid gas	CO_2
2. Nitrogen	N_2
3. Carburetted hydrogen	CH_4(marsh gas)
4. Carbon disulphide	CS_2
5. Sulphuretted hydrogen	H_2S
6. Ammonium sulphide	NH_4S_2
7. Watery vapour	H_2O

Carbonic acid is usually present in sewer air. In mines it is known as choke damp. It is very deadly, and if in a concentrated form will cause almost immediate death. It is generated during decomposition by oxygen combining with carbonaceous matters. It may even be found in excavations, such as those in old burial-grounds. Nitrogen is present in sewer air in excess, owing to the absorption of oxygen by organisms and liberation of the nitrogen as gas. It is not poisonous. Carburetted hydrogen is dangerous, as it is explosive. It may arise from the decomposition of sewage in a sewer, especially from decomposing vegetable matter, but its presence is generally ascribed to the leakage of neighbouring gas pipes. Sulphuretted hydrogen is a well-known gas (H_2S). It is present in sewage and other decomposing matter, and is the usual cause of "bad smells." It is very poisonous, and is heavier than air. It is absorbed by charcoal, if dry, and iron oxides, and for this reason Mr Baldwin Latham used charcoal in the ventilator illustrated in fig. 138. This ventilator will remove a nuisance from a manhole which gives off bad smells by absorbing the H_2S gas; but as the charcoal must be kept quite dry if it is to be effective, these ventilators have not proved so useful in practice as might be expected. In the ventilation of sewers by natural means there are two very important agents constantly at work, viz. heat and the fluctuation of the level of sewage in the sewer. The term "natural" is opposed to artificial ventilation by means of fans or heated shafts. There have been many attempts to design elaborate systems for ventilating sewers on the same principle as mines, but those responsible for the ideas evidently did not know the condition of sewers as opposed to mines. The reader should bear in mind, once for all, that artificial ventilation for sewers has been found an impossibility. There are so many openings through which air will leak, and so many bad traps on house drains liable to be unsealed by the slightest vacuum, that the remote parts of the mains and no part of the smaller branch sewers would have anything like the flow of air required to cause proper ventilation. In any case, the plant necessary for this and its cost of upkeep would be something enormous. Hence sewers must be kept free from foul air by natural means. This is not a difficult matter if certain points and laws are followed, especially when the sewers are laid, as they should be, with self-cleansing velocities, which will prevent stagnation. Heat, as stated before, is a powerful agent at work within a sewer, and in any *un*ventilated sewer is capable of developing a force which no trap would stand. Hot water is constantly pouring into sewers to create this heat. The difference of temperature between the external atmosphere and the internal air of a sewer is one of the forces at work by which the ventilation of sewers is effected. From observations in Dublin, the author found that, on an average, the sewer air was 3° colder than the atmosphere in summer (shade temperature), and in the winter 9° warmer. In the autumn it is about 2° warmer, while in the spring there is very little difference. The Irish summer and winter are not very hot or very cold. Towns which are supplied with well-water will be found to have a more uniform sewer temperature than towns supplied with surface-water. Again, the varying level of the sewage is a most important factor, owing, as stated, to the bellows action it exerts, whereby the sewer air is compressed or dilated as the case may be. According to the law of the diffusion of gases, the pressure is inversely as the space occupied, therefore it is quite clear that unless openings are made as outlets and inlets the natural rise and fall of the sewage must draw in and expel foul air at points out of control—that is, the house traps. Sudden storms cause a rise of pressure, as also does the flood tide in tide-locked sewers. Finally, the rise and fall of the barometer is an influence on sewer ventilation which must not be lost sight of. A fall increases the escape of gas which is held in the sewage, while a rise permits of sewer air holding more watery vapour, and watery vapour makes the air lighter. Seeing, then, that there are so many forces at work, the reader will be able to understand why no elaborate system of upcast and downcast shafts has met with much success. Most engineers are now content to use open manhole covers in the streets, with, perhaps, an air shaft at the head of a line of sewer, and to allow natural forces to do the rest. The writer has always found this simple project to act well in practice, especially when the sewer air is divided into ventilating zones by manholes, such as that shown in fig. 147.

The Interceptor Trap.—There are many advocates of the disuse of the interceptor trap. They urge, as a strong point, the numerous points at which the sewer air would find exit—that is, up all the soil pipes and over the eaves of houses. To the writer's mind there are two strong objections:

1. The pipes, being all cold in winter, would actually impede the otherwise natural ventilation.

2. Who is to see that every soil pipe is perfect? Even if it were so at first they may easily go wrong, and why should each private individual remove gas which has been supplied by the public at large?

The use of open manhole covers in the roadway has many points in its favour. The gases become so diluted on escape that they cease to be dangerous, or even unpleasant, except to a certain class of persons who imagine they can smell everything; 90 per cent. of the complaints of smells which local surveyors receive are pure imagination. Open manholes act as air inlets and air outlets.

Sewer Air.—According to Mr A. J. Price, "Sewer air may be, and after a storm generally is, perfectly harmless and free from smell; for the decomposing deposits in the sewers, which generate and give off offensive gases, have then all been washed away by the storm water. The writer has on several occasions after a storm walked through large sewers in which no offensive smell or any evidence of sewer gas could be found. He has, however, too often experienced the presence of sewer gas in these same sewers in dry and hot weather to have any doubts as to its offensiveness, or its danger to health.

"Sewer gas is largely composed of sulphuretted hydrogen, carburetted hydrogen, carbonic acid gas, and other poisonous compounds, which vary according to the manufactures and other conditions of the locality. Chemical wastes, coal gas, and other matters have frequently led to explosions in the sewers; and as many workmen have lost their lives from these poisonous gases, it hardly seems possible to doubt their dangerous qualities, or to dispute the necessity of dealing with them in such a way as to render them less dangerous, if not altogether harmless."

A much less quantity is evolved when the temperature is low and the sewage is diluted and flowing through the sewer freely. Again, the atmosphere has an important bearing on sewer ventilation. It is well known that air expands when heated and contracts when cooled; the warm air, by reason of its lowered density, will rise; in other words, diffusion takes place due to the difference of density between the cold and warm air, which applies to gases of different densities at the same temperature; they will intermingle and produce a uniform mixture. Watery vapour is lighter than air, and water exposed to air continues to give off such watery vapour till the air becomes "saturated." This term is applied when tension of the vapour in the air=the tension of the vapour at the water surface. The warmer the air, the higher the saturation point. The ordinary composition of atmospheric air is $\frac{1}{5}$ of oxygen to $\frac{4}{5}$ of nitrogen; 13 cub. ft. of air=1 lb; ∴ $13 \times 62{\cdot}5 = 812$. Air is 812 times lighter than water.

Obviously the air in a sewer is always in a state of saturation, and the quantity required for this will be increased in the event of the sewage being warm, which is often the case, due to steam and hot waste manufactures being let into the sewers; in any case, trade refuse will always assist in producing bad gas. In London it is an offence to discharge hot liquids into the sewers: the practice of blowing off boilers into the sewers is barbarous and highly dangerous. Some valuable experiments on sewer gas are recorded by Dr W. J. Russell, F.R.S., who stated that from specimens collected in various street and house sewers in Paddington (1869 70) in August, "The most impure air that was examined contained 0·51 volume of CO_2, 2·7 oxygen, and 78·79 nitrogen, in 100 volumes, or, as compared with ordinary atmospheric air, the nitrogen was rather less in amount, the oxygen a little less, and the CO_2 about twelve times as great. . . . This air was not very much more impure than that in many crowded rooms." When sewer gas is passed through cotton-wool heated to about 10° above boiling point, a microscopical examination will usually indicate a freedom from organic bodies; at the same time the spores of several fungi may be found to be present. In fact, Mr Russell's investigations proved sewer air to be less harmful than is commonly supposed, especially bearing in mind that in the height of summer, when the samples were taken, it would be naturally at its worst. A natural movement of sewer air is always in action. It is principally caused by the bellows action of the rise and fall of the water-level in any sewer, and the tide-level in sewers which are affected thereby. Again, in winter the sewer air is warmer than the external atmosphere, and tends to rise at high levels and be replaced by colder air at lower levels; it has, in fact, been proved that outbreaks of disease have occurred in a worse degree in high parts of a town than low parts, especially in the case of unventilated sewers. It must also be remembered that although sewer gas is dangerous by its carrying fœtid organic vapour, caused by decaying sewage and slime in sewers, yet it does not necessarily *cause* typhoid and allied diseases, in the opinion of the medical profession, but rather has the effect of indirectly causing disease by lowering the vitality of those who inhale it continuously, due to the presence of highly poisonous chemical substances, often of an alkaloid nature, and an excess of CO_2. In addition to the causes given, the evolution of sewer gas may be due to rapid changes of barometric pressure and sudden variations in the temperature of the atmosphere, a rise of temperature after a heavy rainfall having a double effect of the bellows action referred to, and the extra chances of decomposition at high temperatures. Mr Dibdin says: "The want of sufficient water carriage is one of the principal causes of nuisance. However offensive sewage may be when stagnant, it gives off little offensive effluvium when it is fresh and largely diluted with water flowing at a fair velocity. The extent to which it is diluted determines the degree of offensiveness of the sewage itself, and swiftness of flow removes it before material decomposition sets in. Hence it is necessary for the engineer, in order to cut down the production of sewer gas to a minimum, to construct his sewers so that a continuous flow shall always be maintained in them, and, if necessary, provide ample flushing, in order to dilute decomposing matters in them, and remove such matters quickly." Tide-locked sewers will always be liable to bad gas; at the same time, it is quite possible for sewers to have too great a velocity, especially small ones, with the result that the solids are left behind to decompose.

Constructional Defects in Sewers.—Badly formed sewers are conducive to the production of sewer gas. As advised in the previous chapter, in connecting with built sewers, proper junction blocks must be provided which will give the liquid from the branch sewer a gentle run into the main in the direction of flow. More will be said on the question under House Drainage. In the case of pipe sewers joining when they are of different diameters, it is a wise rule to keep the soffits of both pipes at the same level. It will compensate the loss of fall due to the entry of sewage from the small sewer.

The junction of two brick egg-shaped or circular sewers demands much ingenuity to get continuous flow. The effect of a bad junction is to cause splashing; and although sewer air is not supposed to take up organisms from the sewage, yet the splashing will cause evolution of bacteria, which will be carried along by the current of sewer air. Bad, absorbent brickwork and concrete give off bad gas. Although sewer gas is known to rise by reason of its lower specific gravity, yet this property must not be relied upon too much in designing a system of sewer ventilation. The general principle should be to relieve the pressure of the gas in the sewers, and dispose of it in as diluted a state as possible. The obviously simplest way is to make numerous openings along a line of sewer to surface-level. The pressure in these openings will vary very little, and there will not be any chance of house traps being forced by pressure, but these outlets (the openings are designed primarily as outlets) will often act as inlets, a contingency usually out of control of the designer. If there are no means of relieving the pressure of air in a sewer, there is liability, perhaps remote, of the house interceptor traps being forced; and if such traps do not exist, it finds a ready means of exit into the house systems; hence the necessity of the interceptor. As will be discussed under House Drainage, there are many who do not advocate such a trap, but who consider that the air-shafts of each house will at all times act as efficient sewer ventilators. No doubt this might be the case, but why invite the enemy (sewer gas) into a house system at all, in view of the possibility of a hitherto undetected faulty joint admitting it into the house, or why should a private individual contract to take the risk of disposing of so much sewer gas when he pays rates for other people to do it for him?

The ordinary flap valve, sometimes substituted for the interceptor trap, is rarely, if ever, proof against the passage of air under pressure, while the warm house air is always tending to induce such air into the house. Another plan, which is extremely dangerous, is to connect rain pipes direct to the *sewer* (direct to the *drain* is bad enough), so as to assist ventilation. Rain-pipe joints are never tight, in fact they need not be, and sewer air is sure to find its way into the house by open windows. Again, in view of the recommendation of all junctions to be low down in the main, where is the air in the sewer to find an outlet when, after a heavy rainfall, and such ventilation is most needed, the water-level is about the soffit of the junction pipe? Finally, the practice of connecting sewers with furnace chimneys, with a view to assisting removal of air, has been found ineffective, which proves that the only really reliable method is that of manhole shafts, and in some cases tall iron shafts at the head of the sewer.

Importance of Ventilation.—This is upheld by Dr Buchanan, reporting on the question in reference to the epidemic of enteric in Croydon, 1875. He says: "Where sewers are small and ill-ventilated they constitute perfectly sufficient means for the rapid distribution of fever infection, and places having such sewers may not only show fever rates maintained as high as before the sewers were made, but they may show as smart outbursts of fever as are witnessed where conveyance through water or by milk is in question. Croydon itself, after it had made its sewers, and before it attempted to ventilate them, had this experience. So, in other instances which have come under my knowledge, fever has maintained itself after pipe sewers, ill-ventilated, had been laid, as in Rugby, Carlisle, Chelmsford, Penzance, and Worthing. Towns with larger sewers have not appeared to have the same suddenness of outbreak when spread by means of sewer air has been in question. In them the evil . . . is more gradually manifested. . . ." The displacement of air in the smaller sewers is greater than in the larger ones, and also more sudden, and hence the necessity of relieving the pressure in such sewers. Regarding the question of adequately diluting the air so displaced into the atmosphere, the same authority states: "But at least as important a further object to be obtained by the ventilation of sewers is such dilution of sewer air as shall reduce to the utmost its harmful qualities. These harmful qualities are popularly measured by smell, and if there be no sewer smell, people think little of danger from a sewer. The popular view may be true enough of such minor harm as may come from ordinary excrement decomposition, but it is certainly not true of such greater harm as comes from the specific infection of a sewer. . . . Want of due distinction between stink and infectiveness has led to this consideration being overlooked in practice." Again, still considering the effect of infection, Mr D. K. Clarke says, in reference to the difference in death rates of towns having steep gradients and towns having flat gradients, "Some of the former had high death rates, and some of the latter had low death rates. Portsmouth, which is comparatively flat, with its barracks, constantly appears in the Registrar-General's returns as having one of the lowest death rates. . . . Hull also, with its flat site and unventilated sewers (1889), frequently stands very low. Liverpool, many years ago, when the sewers were not ventilated, had a death rate notoriously high. But after they were ventilated under Mr Deacon's management, the death rate from those zymotic diseases which are generally believed to be directly influenced by sanitary improvements showed a marked reduction. Ventilation showed a diminution of the zymotic death rate of 46 per cent." Liverpool is a hilly town.

Now, in any system of sewer ventilation, the aim of the designer should be to ensure that its operation is as constant as possible, at the same time causing the greatest possible change of the sewer air, with the minimum risk of nuisance. The conditions of efficient ventilation in sewers are very complex, and hence a perfect system has not yet been found, and the least imperfect of all is that of shafts leading from the crown of the sewers to the centre of the road, and covered at the road-level by an open grating. The system, as is only too well known by town surveyors, is liable to complaint from the ignorant public who smell (or more often imagine they smell)[1] bad odours. Adequate flushing is also a great aid in the assistance of proper sewer ventilation, and the elimination of road sweepings and manufacturers' waste as far as possible is of further advantage.

Flushing is best done at the heads of branch sewers. It is frequently found that when bad smells emanate from a particular section of a sewer, that near to them will be found an obstruction which must be removed. Hence the advisability of avoiding such obstructions. It may, of course, be due to the sewer being of faulty construction, or the number of manholes may be inadequate. The ventilator at the head of a long sewer may give rise to a nuisance from this cause, for which the remedy is obviously to provide more outlets. This is especially the case in view of the fact that the least volume of sewage flows at the head of a sewer, while the greater volumes at the lower ends draw in air by way of the surface ventilators, this air, travelling up the sewer, becomes fouler and fouler as it becomes deoxidised, and finally emerges in a very foul state at the head.

Ventilators.—Although, as a general rule, shafts of small diameter are considered by practical engineers (the theory sounds well enough) to be of little or no use, the air, more often than not, merely oscillating within them, yet for this particular purpose they have the advantage of removing risk of nuisance from surface ventilators; at the same time they are always dependent for their action on the direction and velocity of the wind and the atmospheric temperature. They should be circular in section to reduce resistance to a minimum, have no elbows or bends, and be of fairly large diameter. The resistance varies as the length, and inversely as the diameter; and on this assumption an empirical formula has been deduced giving the approximate velocity therein dependent on the difference of temperature between the sewer air and the atmosphere.

Let d=diameter of shaft (inches).
h=difference of level between inlet and outlet (inches).
t=difference of temperature between sewer air and atmosphere.
c=0·025 for cast iron.
V=velocity in feet per second.
l=length in inches.
Then

$$V=\sqrt{\frac{0{\cdot}13dht}{d+cl}}.$$

The standard design is shown in fig. 137. The shafts are usually surmounted by a netting of pure copper wire in the bell mouth to prevent obstruction by birds' nests or other cause. A rust pocket is also essential. For use in place of the shaft, where nuisance would be likely to exist at the surface, there is on the market a manhole designed by Mr Baldwin Latham. It is shown in fig. 138. The system consists of a spiral tray placed below the cover, which is filled with charcoal, through which the foul air is expected to pass and become oxidised. Dry charcoal is known to have a power of decomposing the H_2S and ammonia, and rendering the air quite harmless. Unfortunately the apparatus will become quite inefficient unless the charcoal is frequently renewed, because it soon becomes clogged and damp, and then the air ceases to flow out through it. In any case, they require recarbonising every two months or so.

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[1] *Vide* Wood, *Sanitary Engineering*, p. 122, 2nd ed.

An ordinary form of ventilating manhole cover is shown in fig. 139.

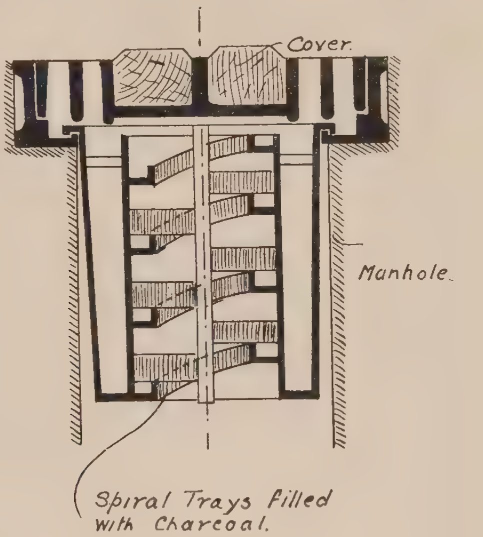

FIG. 138.

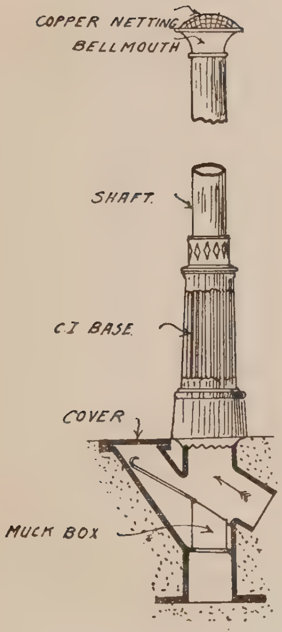

FIG. 137.

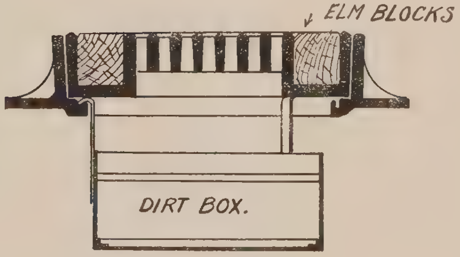

FIG. 139.

Tall shafts may, to a limited extent, be assisted in their power of extraction by some form of cowl or other (not mechanical) means, which depend for their action on the passage of the wind over specially formed vanes. A form much in use for soil pipe ventilators is that shown in fig. 140, and known as Steeven's cowl. But perhaps the best known are Boyle's "air-pump" ventilators. For extracting air they certainly have a wonderful power. Made of sheet steel, they are of two forms, the extracting or "upcast" cowl and the "downcast" cowl. The former is shown in figs. 141 and 142, and the latter in fig. 143. Applied to sewer ventilation, the patentees advise the method shown in fig. 144, which is on practical lines.

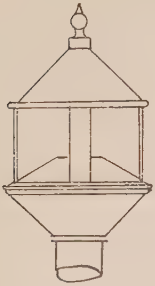

Fig. 140.

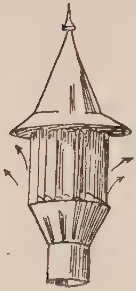

Fig. 141.

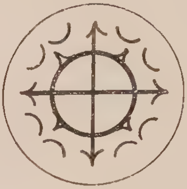

Fig. 142.

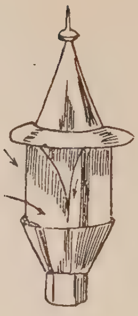

Fig. 143.

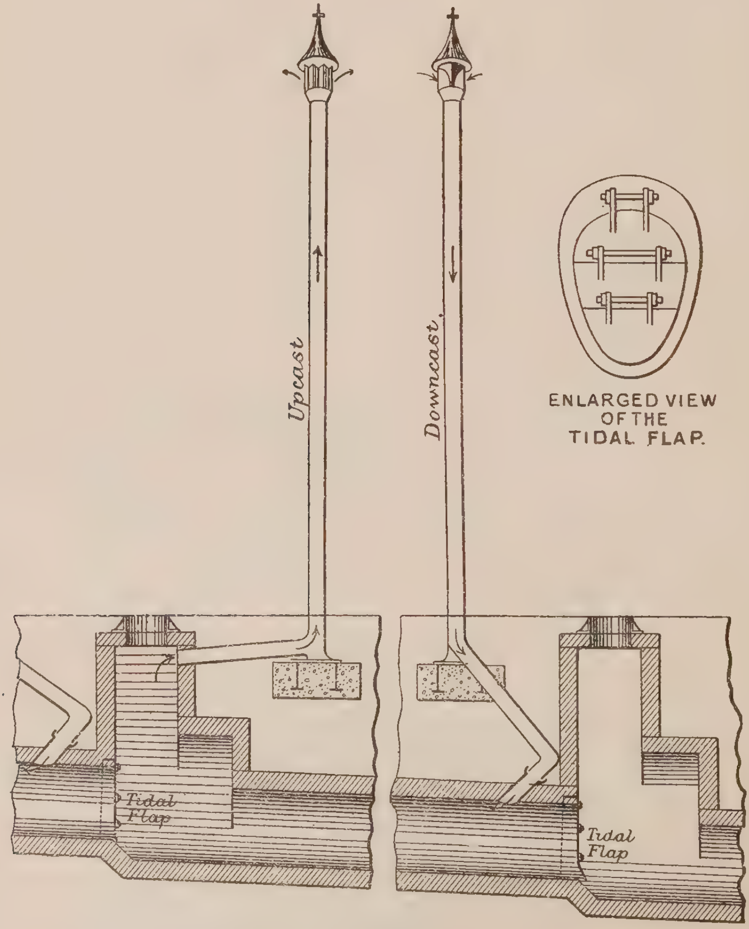

Fig. 144.

Surface ventilators need not, of necessity, be in the centre of the roadway, directly over the crown of the sewer. Even when designed with a dirt box or chamber, which is quite essential with a surface grating, the manhole cover is likely to get choked unless cleaned frequently. To obviate this, many engineers prefer to use close covers, and to bring the ventilating pipe to the side of the road, and terminate it with a special grating in the kerb of the footpath, as shown in figs. 145 and 146, a system which has much to recommend it, yet it is open to the objection of untrapped gullies, viz. possible nuisance to pedestrians.

On the whole, there is no doubt that the most practical method of sewer ventilation is that advised by Sir Robert Rawlinson, in which the system is divided into ventilating zones by locking the air in the sewers and providing air-intercepting traps and shafts above them. In any case, a large sewer having a gradient of more than 1 in 200 or so, and over a mile in length, should be divided by steps or falls (*vide* next chapter), with a flap valve on the upper end and ventilating gratings at this point. The idea is shown in fig. 147. The trays, filled with charcoal, may be employed at the engineer's discretion. The illustration in question shows a manhole of this description for a 2 ft. 6 in. egg-shaped sewer, and a light aluminium flap would be employed. This is an expensive form of construction, which may be modified with equal efficiency into the form shown in fig. 148. Two hundred yards apart is an advisable distance for surface ventilators, but it is not usual to find them so close. The theory has been advanced that sewer air undergoes a sort of purification on the same principle as that of the bacterial treatment of sewage. That is to say, the organic matter present is decomposed by the action of micro-organisms into nitrites in the first stage and into nitrates in the second. Such may or may not be the case; the author is not in a position to debate the question; suffice it to say, that it has been the means of stimulating invention towards evolving systems of deodorising sewer air. On the whole, it seems that such systems are doomed to failure, because any apparatus of a "fancy" nature is best avoided in a sewerage system. For the benefit of the reader one may describe Reeve's system, which consists of two earthenware pots placed in the manhole chamber. One of these is filled with strong H_2SO_4, while the other contains manganate of soda. Below is placed another pot. Water is allowed to drip slowly on to the manganate of soda, the solution falling into the lower jar. Into this also, at a suitable predetermined rate, trickles the H_2SO_4. A chemical action takes place, in which large quantities of permanganic acid are evolved, the gas itself being a very

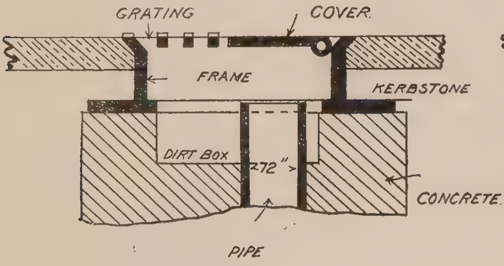

FIG. 145.

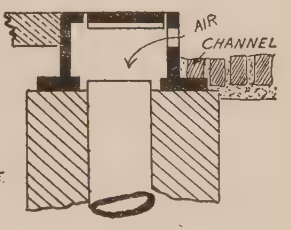

FIG. 146.

powerful deodorant. A very fine water spray is introduced which causes a sort of mist. This, falling by its specific gravity, meets the upward flow of sewer gas and so purifies it, while the solution which falls into the sewage assists in oxidising the same. The apparatus costs about £20, and its maintenance from 45s. to 50s. per annum for upkeep.

A simpler system is Shone's. A water jet in a sort of conical arrangement acts as an ejector and draws the air out of the sewer, washes and purifies it, and finally discharges it into the atmosphere. The water runs to waste.

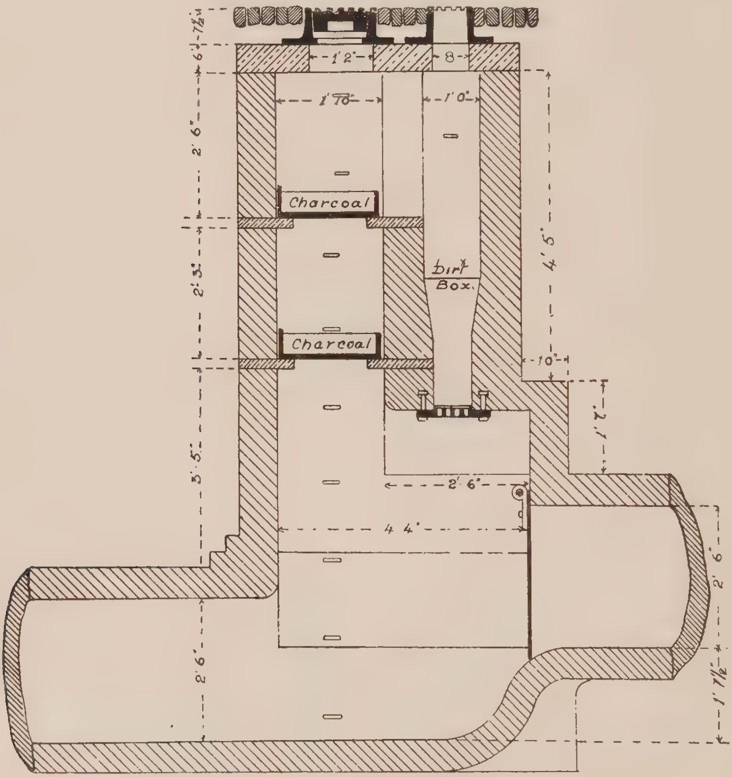

Fig. 147.

A system which has been tried with fairly good results is Shone and Ault's, which is used in conjunction with Shone's ejectors, described in Chapter IX. The exhaust from the ejector runs to a nozzle at the foot of the ventilator shaft, which is connected to the nearest manhole by a fireclay pipe. The shaft is of the usual pattern, about 30 ft. high. Upon the ejector being filled with sewage the air is expelled into the nozzle, which then acts on the ejector principle, drawing in air with it from the sewer by means of the fireclay pipe, by reason of the partial vacuum so formed. When the ejector is filled with sewage and the compressed air is allowed to enter, the exhaust valve closes automatically, and the whole volume of compressed air rushes through the exhaust, carrying with it air from any sewer with which it may be in connection. If the sewers are short, the fresh-air inlet has to be closed to the smallest extent; and if long, it is opened proportionately; by this means the bulk of air drawn to the nozzles is proportioned to the sewers. There must be no air-openings into the sewers except the one that is regulated. The system has the disadvantage that, in dry weather, surface traps may be unsealed.

Movement of Sewer Air.—Some useful information on the movement of air in sewers has been brought to light in a paper by Mr W. Santo Crimp, M.Inst.C.E.,[1] and is based on experiments carried out at Wimbledon. One of the three main outfall sewers at Wimbledon provides for the collection of the sewage from the most hilly portion of the district, and frequent complaints were received as to the foul gases escaping from the outfall, which for a considerable length is constructed under a comparatively level road, much used by pedestrians. The branch sewers, for the most part, are at right angles to the main sewer, and pass up hills with gradients varying from 1–8 to 1–100. From the above description the reader will observe that the system is very typical of what occurs in the sewerage of residential districts. On the complaints being received and considered, the engineer advised the trapping off of each branch from the main outfall. This was done by a syphon trap, having an air-inlet shaft immediately above it. During hot weather, which occurred soon after the carrying out of the work, it was found that the sewer air frequently poured out of the air-shafts, showing, first, that the air was often passing down the sewers; and secondly, that the complaints with regard to the outfall were most probably due to the fact that this sewer was frequently the receptacle for the gases generated in the branches.

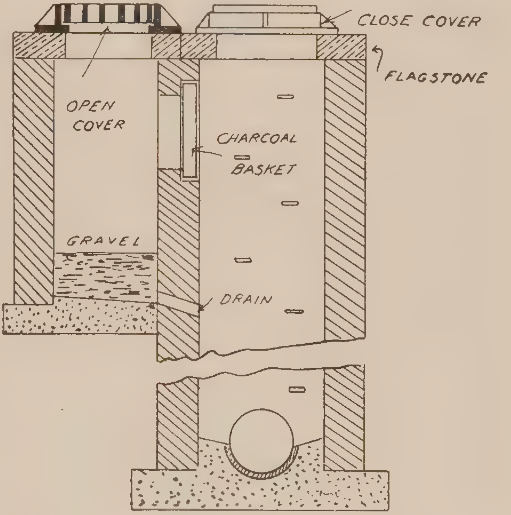

FIG. 148.

The first experiment was made on the 1st of July 1887, when an anemometer was placed in an air-shaft at 12.30 p.m., and at 7 p.m. had recorded an average downhill velocity of 104 ft. per minute; at 9 a.m. on the 2nd the average velocity, also downhill, due to the fourteen hours, amounted to 42 ft. per minute. The air-shaft is 6 in. in diameter.

About the date mentioned, an experiment was made at Wimbledon, in which an "Electrolyser" in conjunction with a "Capell" fan was employed. The capacity of the fan was 18,000 cub. ft. per hour; the length of 12-in. sewer operated upon was 620 yds.; the street gullies were connected with a separate drain; many houses draining into the sewer were provided with traps, others were not, whilst it is probable that in some cases—those of the older houses—the drains act as sewer ventilators; the conditions were, in short, such as are generally prevalent, except in new streets where the houses are drained in accordance with the model by-laws. The fan was connected with the sewer at its uphill termination. All the manholes and ventilators on the sewer to be experimented upon were closed, with the exception of that at the foot of the hill, which was one of the air-shafts already referred to.

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[1] *Trans. I.C.E.*, vol. xcvii.

The air was found to be passing steadily down the sewer; and on setting the fan to work as an extractor, no effect was observable at the foot of the hill, showing that the fan procured its supply of air from the sewer at a point or points remote from the air-shaft, and that, for the time being, air was passing out at both extremities of the sewer, and into it at some intermediate points; that, however, at the top of the hill being withdrawn by artificial means. Had the sewer been air-tight and all connections trapped, the fan would have changed the aerial contents of the sewer in five minutes.

An anemometer was next placed in the air-shaft of the sewer of an adjoining hill, when an experiment, extending over twenty-four hours, gave a downhill velocity of 52 ft. per minute, the air-shaft being 6 in. in diameter. The fact that sewer air passes up sewers is well established, and the author determined to endeavour to ascertain the conditions under which both the upward and the downward movements were effected.

A small brick chamber was constructed adjacent to the air-shaft of the sewer experimented upon by Fewson's apparatus; a central division was built, provided with two openings, with a mica valve, but on opposite sides of the wall. An anemometer was placed in each opening, and all the sewer air passed through one, while all the fresh air entering the sewer passed through the other. Two self-registering maximum and minimum thermometers were employed in the sewer, one for ascertaining the temperature of the sewage and the other that of the sewer air. The latter was suspended at a point distant about 250 yards from the downhill termination of the sewer.

At the end of the sewer a 6-in. ventilating pipe is carried above the roof of a house. The end of the pipe is not provided with a cowl. The ventilating grate openings on the air-shaft at the syphon trap have an area of 28 sq. in. During the period of twelve months, whilst the experiments were being made, the street ventilators were closed with the exception of one, the air-shaft. The depth of the sewage is rarely greater than 2 in., the gradient being sharp.

At the outset, it may be stated that currents of sewer air are frequently too feeble to cause an anemometer to work, and as a consequence there were many occasions on which negative results were obtained; but, on the other hand, the positive results are such as to show beyond doubt what is the principal agent causing movements of sewer air.

The observations were taken at 9 a.m. on each day; they were commenced on the 11th of January 1888, and were continued for one year.

The general results have been placed in a tabular form, as given on p. 125.

With regard to temperature, the close approximation of the average temperature of both sewage and sewer air to the mean temperature of the ground at a depth of 10 ft. (the depth of the sewer), and the periods of the year at which the maximum and minimum are respectively attained, prove that the earth with which the sewer is surrounded is the principal factor in effecting changes of temperature: when it is considered that in the case of branch sewers, of which a complete main-drainage scheme chiefly consists, the whole of the exterior of the sewer is in intimate contact with the soil, whilst but a small portion of the invert is subjected to the influence of the sewage, it will be conceded that the proposition is quite consistent with the facts of the case.

The temperature of the ground at a depth of 10 ft. varies with the seasons. The summer heat is slowly conducted downwards, and the maximum is reached about the end of August; as the temperature of the air falls on the approach of winter, so the heat stored in the ground is given up, and the minimum is reached about the end of February. The exact periods at which the extremes occur will naturally depend upon the weather. Now, an examination of the table will show that the range of temperature of both sewage and sewer air follows very closely the changes in the temperature of the earth at a depth of 10 ft.; the maximum monthly temperature of the air occurred during the month of August; the sewage attained its maximum temperature in September, while that of the sewer air is practically the same during both August and September.

Table XXI.—Sewer Air Experiments, Wimbledon, 1888.

Month.	Temperature. Air.	Temperature. Sewer Air.	Difference.	Temperature. Sewage.	No. of Days.		
					Up.	Down.	Both.
January .	35°·75	42°·70	+6°·75	46°·30	13	12	8
February .	34·75	42·30	+7·55	44·75	19	29	19
March . .	38·50	42·10	+3·60	45·41	13	27	11
April . .	43·50	44·50	+1·00	47·60	19	30	19
May . .	52·00	49·20	−2·80	50·10	11	26	11
June . .	57·70	54·25	−3·45	53·90	3	27	3
July . .	58·00	56·65	−1·35	54·80	2	28	2
August .	59·10	57·75	−1·35	55·65	4	27	4
September .	55·80	57·70	+1·90	56·70	5	20	5
October .	44·70	53·10	+8·40	51·25	3	12	1
November .	46·40	50·65	+4·25	48·30	5	26	5
December .	41·00	48·85	+7·85	40·60	. .	9	
Means .	47·26	49·98	. .	49·61	Totals 97	273	88

With regard to the question of temperature as causing movements of sewer air, it has generally been supposed that the movements were principally due to that cause. If the assumption were a correct one, the sewer air would pass upwards in winter and downwards in summer—that is, speaking generally. The movements would be most rapid when the difference between the temperature of the air and that of the sewer air was greatest. Now, in the author's experiments, the greatest difference was found to be in October, when it averaged 8·4°, yet during that month the uphill currents were too feeble to affect the anemometer except upon three days. During the same month downhill currents were registered on twelve days.

During the entire series of experiments the actual volume of air recorded as passing downhill exceeded that recorded as passing uphill by very nearly one-third, whilst downhill currents were recorded on two hundred and seventy-three days as against uphill currents on ninety-seven days.

The cases given could be multiplied if desirable, but throughout the whole series of experiments the same effects of the wind were observable; the direction of the sewer-air currents was determined by that of the wind, whilst the currents were either strong, or weak, or imperceptible, according as the wind was fresh or light, or calms prevailed.

In order to test the matter still further, the author experimented upon other sewers, and also upon surface-water sewers which were connected with trapped street gullies and trapped house drains only, and which at the time of experimenting contained no water. In sewers apparently alike, the direction of the currents was, in some cases, found to be downhill, whilst the currents in the test sewer were at the same time going in the opposite direction. In gusty weather the currents were at one moment rapidly uphill, and then suddenly the direction would be reversed, this occurring again and again in the space of a few minutes. One sewer experimented upon was a comparatively new one, and all house connections were trapped off, whilst the street gullies were connected with a separate sewer. With a westerly wind the currents were prevailing downwards, whilst N.W. winds caused principally uphill currents. In a large brick sewer the currents were found to be in opposite directions at one and the same time, at two points not more than 200 yards distant from each other.

CHAPTER VII.

STORM OVERFLOWS, SEA OUTFALL MANHOLES, TANK SEWER MANHOLES, LAMPHOLES, FLUSHING TANKS, AND GULLIES.

The special forms of construction employed in a sewerage scheme, apart from the actual sewers themselves, will now be considered.

Mention has been made of the necessity of dealing with excessive volumes of storm water in order to keep down the size of the sewers and consequent expense, and at the same time satisfy the regulations of the Ministry of Health. It will be obvious to the reader who has previously perused the chapter on Hydraulics that the volume flowing in any sewer is proportional to the depth of liquid in that sewer; hence the most natural thing to do, in order to get rid of the volume of liquid over and above a certain quantity, will be to make provision for diverting it when the water rises to a certain level above the invert of the sewer in question, which is exactly what is done in most cases. It is best done when a sewer flowing at its maximum capacity (for a pipe sewer this would be when half full, and for an egg-shaped sewer when two-thirds full) is just capable of taking away to the disposal works the quantity required by the Ministry of Health. This, of course, wants careful consideration, as already explained. Taking into account the fall and hydraulic mean depth of the sewer, applied to an egg-shaped sewer, such an overflow is shown in fig. 149. The sill shown must be dead level from end to end, and should be made of dressed granite worked to a semicircular or bull-nosed face, or bull-nosed Stafford blue bricks, carefully jointed in neat cement. The outfall sewer may be of any desired shape; circular pipe is usually chosen for cheapness, and the shorter this branch is the better. It is preferable to form the overflow in a large chamber, arched as shown, or covered in by methods to be pointed out as suitable for manholes. It may be deemed by some a disadvantage to have the water falling vertically into the overflow sewer, in which case a simple modification is to make the distance between the centre line of the two sewers greater than that shown, and let the water down a gentle slope. Reference should be made to the formula for water flowing over straight weirs, and sufficient length of weir provided accordingly to prevent the water rising to an inconvenient height on the crest. The parabolic leap weir has been applied to storm overflows. It was previously shown diagrammatically and its theory discussed. The same remarks as above

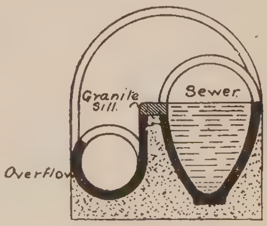


Fig. 149.

apply to construction—that is to say, the part where the water falls over should be made of hard bricks to prevent wear; for the same reason the invert of the outfall sewer should be similarly formed to prevent erosion due to the falling water. Fig. 149 can be applied equally well to a circular built sewer. For pipe sewers other methods are usually resorted to, and a simple form is shown in figs. 150 and 151. The principle is the same as in fig. 149—that is, water rising in the sewer to a certain height above the invert flows over into the storm-water sewer, but in this case a special gauge is formed, in which is a circular passage of a certain diameter. This passage is of such a size, that when working under a certain head (usually equal to a depth above the invert of the incoming sewer, equal to half its diameter) it will pass just the quantity required by the Ministry of Health to pass on to the disposal works. In the illustration this gauge is shown formed in fine concrete and covered with an iron plate. If the gauge was made of iron or bronze comparatively thin (say $\frac{1}{2}$ in.), and bevelled on the downstream side, it would be treated as a circular hole in a thin plate. For instance, the discharge through a circular hole in a thin plate as equal to

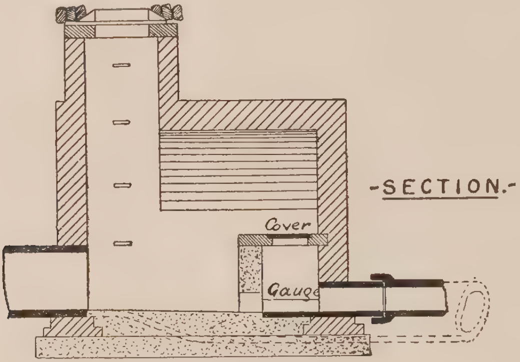


FIG. 150.

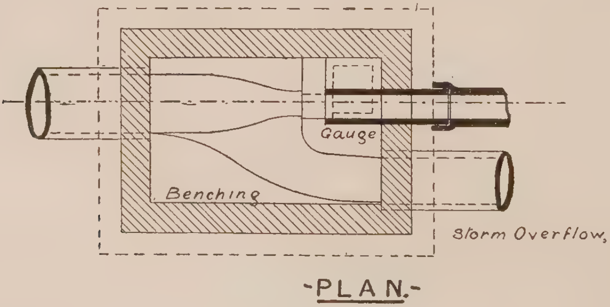


FIG. 151.

$$Q=8{\cdot}025cA\sqrt{h},$$

where $c=0{\cdot}7$. The area of the proposed orifice can be found if Q the quantity of water it has to pass, and h the height referred to, are known by transposing this equation to

$$A = \frac{Q}{8{\cdot}025c\sqrt{h}}.$$

For instance, say $Q=10$ cub. ft. per second required as the maximum flow to the ordinary disposal works. Let $h=1$ ft.=height from the invert of the incoming sewer to surface-level of maximum flow, *less* the distance from that invert to the centre of the proposed circular hole in the gauge plate. Let $c=0{\cdot}7$ and A=square feet.

Then

$$A = \frac{10}{8{\cdot}025 \times 0{\cdot}7 \times \sqrt{1}} = \frac{10}{8{\cdot}025 \times 0{\cdot}7 \times 1} = \frac{10}{5{\cdot}6175} = 1{\cdot}78$$

=a hole slightly over 18 in. in diameter. Such a gauge should be of the *exact* diameter. The disadvantage of this type is that when large volumes are flowing into the storm sewer the value of h is increased, and also Q for a given value of A; but not very seriously from a practical point of view, as it errs on the safe side so far as the Ministry of Health is concerned. For this reason other designs of overflows have been brought forward, one of which is shown by figs. 152 and 153, in which a sliding iron shutter regulates the flow in times of storm and diverts the storm water into a stream or other convenient spot. It is closed automatically by a float in a small chamber at the side. Its size is determined by its ability to just overbalance the weight of the valve when it is suspended by a chain over a pulley. The weight holds up the valve when only small quantities are passing. A heavy rainfall will cause the float to rise and close this outlet. Being automatic, it is a contrivance which the writer does not approve of for sewage works from a practical point of view; at the same time, it might be a useful construction in some places. In any case, there is not much to get out of order. Channel courses should be laid as shown, and the bottom of the manhole chamber filled up with concrete, so as to form an apron over which the storm water will flow to the storm sewer. A good form of overflow is shown in figs. 154 and 155. It is simple and cheap, consisting of a half pipe along the line of sewer, over which the superabundant volumes of water find their way to the storm sewer below; but it wants very careful constructing. The writer has erected some which give satisfaction; but the want has been lately supplied by Messrs Adams & Co. of York, in the shape of a special casting in two parts connected by bolts in slotted bolt-holes,

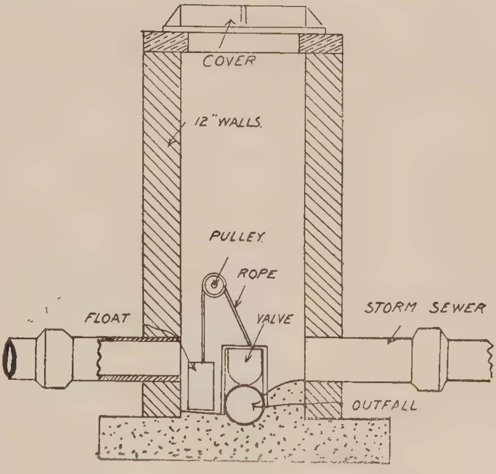


Fig. 152.

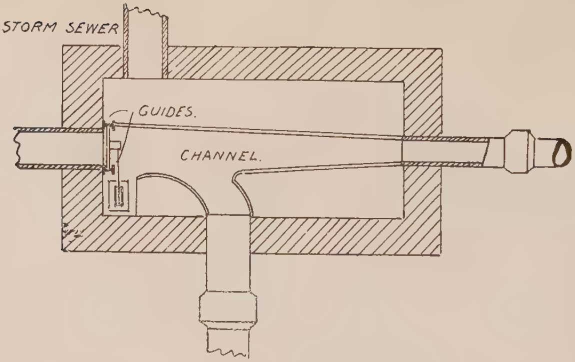


Fig. 153.

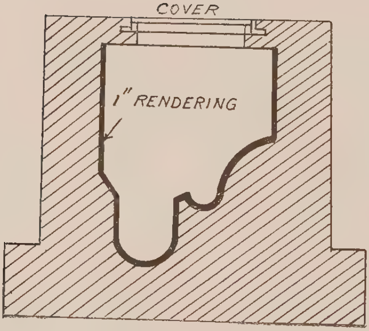


Fig. 154.

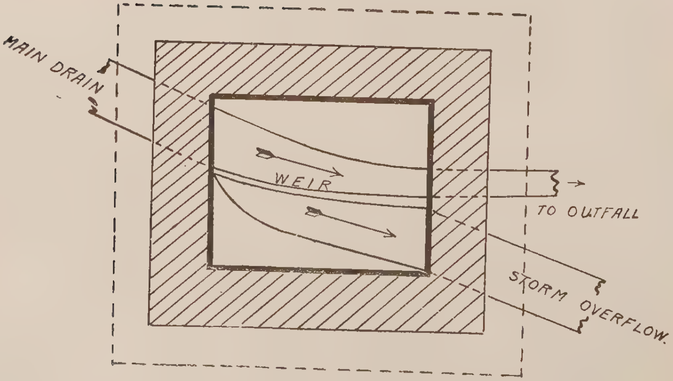


Fig. 155.

by which the height of the overflow lip can be altered at will. It is easily inserted in any line of pipes, and is much more durable than the one formed by ordinary workmen, who, in any case, cannot be expected to work with mathematical accuracy. It is shown in fig. 156.

Mr Wood, in his *Sanitary Engineering*, p. 155, 2nd ed., describes a good practical form of overflow for use where a sewer discharges direct into the sea. It consists of a pipe following the same invert as the main sewer conveying the ordinary flow of sewage to low-water level, so that it will always flow out seawards. Two others, one on each side of the main, receive storm water over weirs and conduct it to half-tide level. On account of its interest, the overflow on the northern outfall sewer of the London main drainage is shown in fig. 157; it is unique. As a rule, the lower channels are closed and the upper ones conduct the sewage to Barking outfall; in times of flood the water flows over the weirs (five in all) into the storm sewer, which empties into the River Lea. In figs. 158 and 159 is shown an adaptation of Adams' syphons for diverting storm water. It would be very useful for dealing with small volumes, for which ordinary

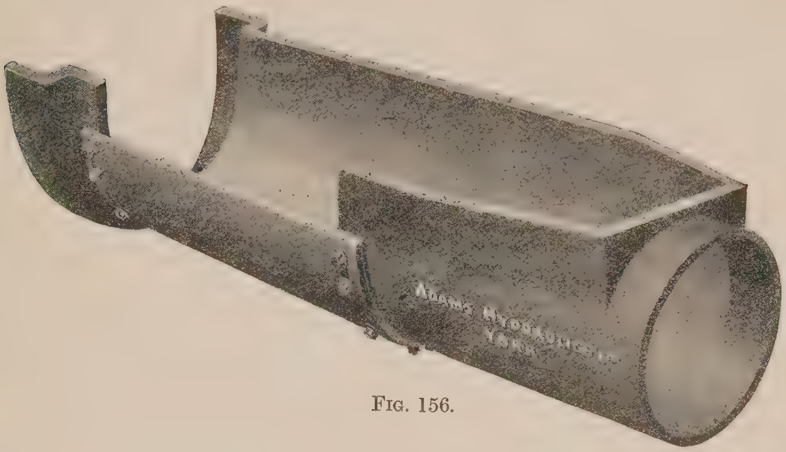


Fig. 156.

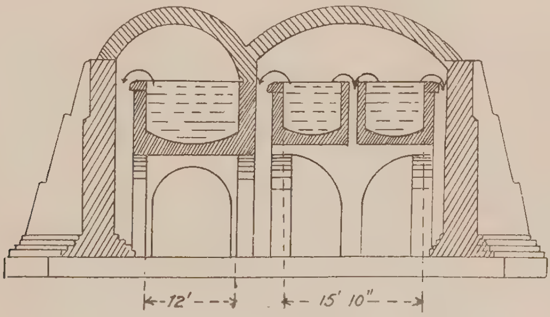


Fig. 157.

weirs are not always quite satisfactory. The apparatus passes the normal supply, but automatically closes against an excess of volume. The entire amount is then discharged by way of the storm outlet, either directly to the nearest watercourse or to special storm-water filters, as may be desired. The advantage of the apparatus lies in the fact that not only are the sewage filters protected from overwork, but also that they get an absolute rest at times when no treatment is required.

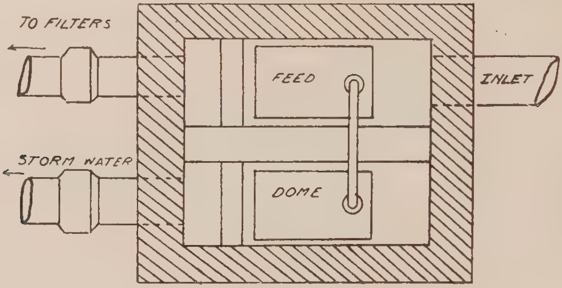


FIG. 158.

Manholes.—In order to obtain access to a sewer for inspection, cleansing, and general attention, chambers are built along the line of sewer and brought to surface-level or other convenient point, and closed by a door or cover. They are called manholes. In order to ascertain if a sewer is clear, it is necessary to see through it, or rather through a section of it between two manhole chambers. This will necessitate the use of manholes at all changes of direction, which is their usual position. To aid the inspection, lampholes are also sometimes introduced, although their use is rapidly going out of vogue. These holes are for the purpose of suspending a lamp to illuminate the sewer for inspection from the manhole, when the interior, if clear, appears something like a rifle barrel, and any obstructions, projections,

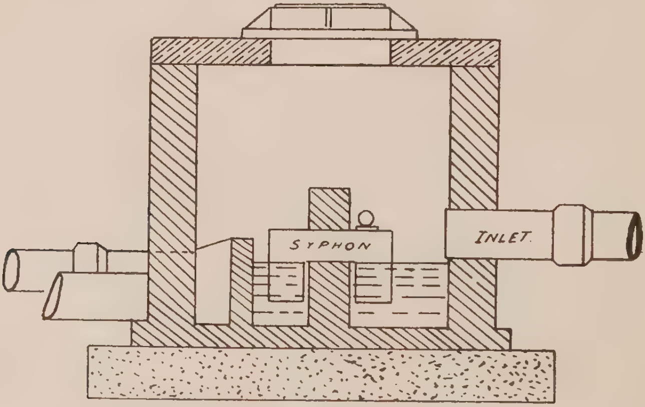


FIG. 159.

or other foreign matters are seen: A lamphole may be useful in long straight lines of sewer, where it would eliminate the use of a manhole. They also assist the manholes as outlet ventilators. Reference will be made in the chapter on House Drainage to small manholes in connection therewith; those used on main sewers are here considered. Starting with figs. 160 and 161, these show the simplest form of manhole for a sewer. Its size should be about 5 ft. long, to admit of a man using drain rods with ease; 2 ft. 6 in. is ample width, while the chamber would need to be at least 4 ft. 6 in. high. It is usual to arch over the chamber at this height, and continue it upwards to the surface-level by a 2 ft. or 2 ft. 6 in. square shaft, or of a width equal to that of the chamber, and surmount the same by a cast-iron cover, close or open as the case may be. The walls would be corbelled in to make the shaft the correct size, and the cover often rests on a flagstone with a hole cut in it to give firm bearing to it. Step irons are let into the walls of the shaft as the work proceeds to enable easy access to be made to the bottom, but sometimes a small wrought-iron ladder is substituted, especially in very deep and large manholes. The usual material employed is ordinary stock brick, 9 in. to 14 in. thick or more according to circumstances, and set in cement mortar. It may, however, be concrete of the same thickness, but not less than 12 in. is advisable. In any case, the base would be of 12 in. concrete or more, and of such a width that the safe bearing power of the soil is not exceeded. In case of a concrete manhole it is not usual to arch it over, but to use one of the following methods :—

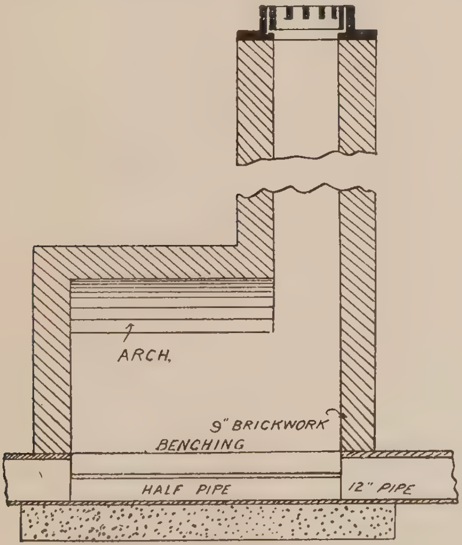


FIG. 160.

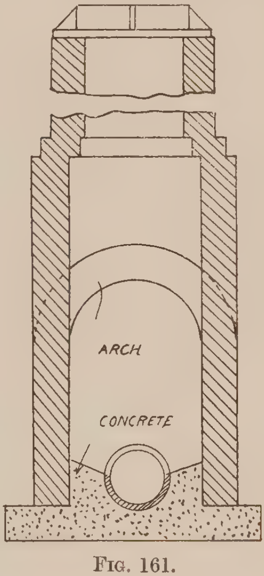


FIG. 161.

1. To make the manhole the shape of a frustum of a cone, tapering from about 2 ft. 6 in. to 5 ft. 6 in. circular.

2. To cover the chamber with a slab of reinforced concrete (see chapter on Sewage Tanks).

3. To use rolled steel joists and turn jack arches between the same.

4. Cover chamber with one or more flagstones.

The concrete manhole made in the form No. 1 is a very effective and inexpensive piece of work. The invert is formed of a half pipe. These are usually cut from the pipes used on the job, but special channels are better. For junctions, curved and taper channel pieces must be used; those white glazed make a nice piece of work, but are not often used, except in house drainage. The sides of the bottom should be banked up on each side of the channel corners at about 45° and finished in neat cement. The covers also demand attention. They are usually of heavy cast iron, coated with Angus Smith's solution. Various forms, open and closed, are used according to circumstances. A very good form is shown in fig. 162, which is well suited to heavy traffic and has wood blocks, usually made of elm, to ensure safety for that traffic. Some covers also have a grating of wrought iron immediately below them, and hinged; and all open covers require a dirt box slung below them to catch any rubbish which might find its way into the sewer and choke it. A light cover may be used in cases where there is no traffic and on footpaths. They should be of the locking type, so as to prevent mischievous people tampering with them. Heavy covers are often difficult to raise when they have been down some time, and to obviate the difficulty Messrs Adams have introduced a patent design which is very effective, and is known as the "Helorf" cover. The invention consists of one or more cross levers so arranged that, when drawn up by means of a hook key, the plug of the manhole cover is raised from its seating, and when thus started it may be readily lifted out. It is also quite essential that all covers should be tight, and not capable of any unsteadiness. It is usual to place three or four radiating courses of setts round the cover frame, set in cement mortar and laid on concrete; but where this is deemed inadvisable, a cover with special flanges on the frame, by means of which the macadam is securely bonded into the frame, makes a very neat and substantial job. It is shown in fig. 163. Lamphole covers are simply small manhole covers, and the above remarks apply to them. A very simple form of lamphole for a pipe sewer is shown in fig. 164, consisting of 9-in. sewer pipes, fitted into an upturned square junction, set in 9 in. of concrete and brought to the surface-level to a proper cover. The application of a lamphole to an egg-shaped sewer is shown in figs. 165 and 166, and set in a special block for the purpose. Such a lamphole is very often necessary on an egg-shaped sewer, because it is not always advisable to disturb the continuity of the crown of the arch with a manhole where such blocks would not be used. In this case the use of the side-entrance manhole shown in fig. 167 is to be advised, and the cover, being

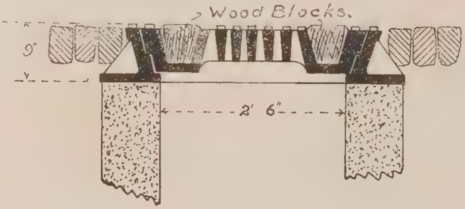


FIG. 162.

in the pavement, is only of light section (preferably hinged), and must be close, in which case the lampholes will ventilate the sewer. The side

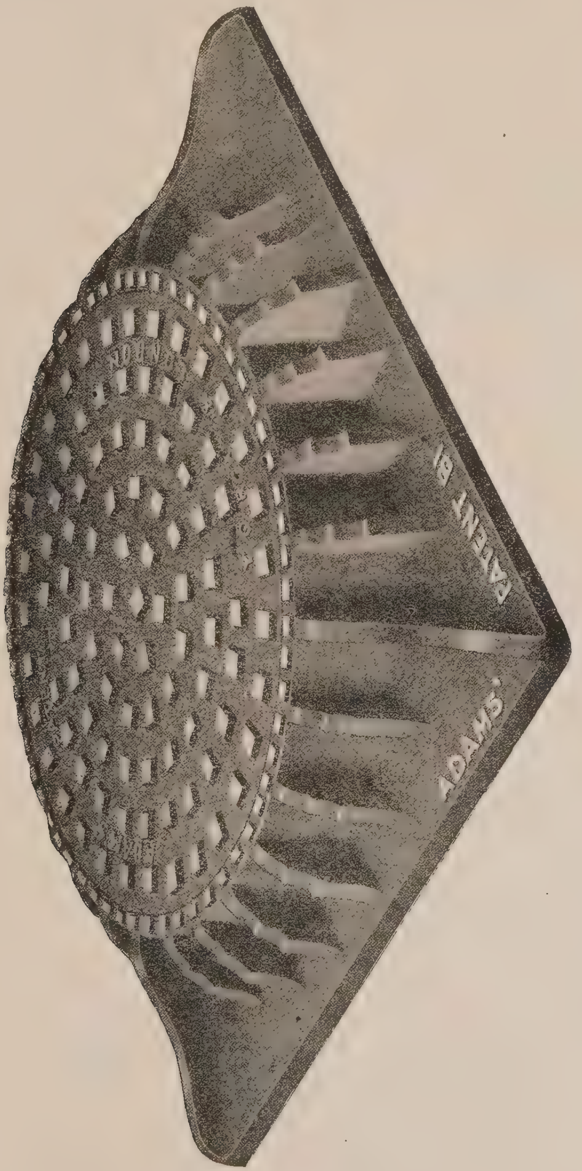


Fig. 163.

entrance also has the advantage that men entering the sewers do not interfere with the vehicular traffic. In main sewers, manholes should always be placed at junctions. In pipe sewers, beyond the use of proper channels, and keeping the soffits of both pipes at the same level as advised, nothing special will occur; but with built sewers great attention must be paid to the brickwork, so as to ensure an uninterrupted flow. A junction for a large sewer is shown in figs. 168 and 169.

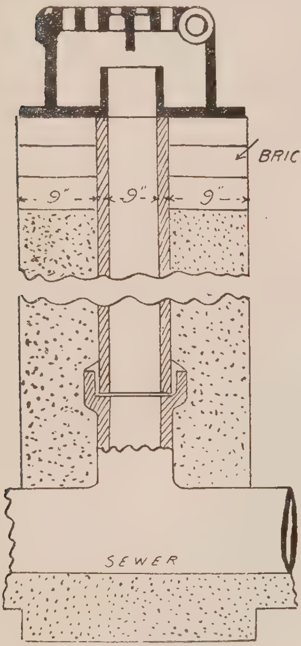


FIG. 164.

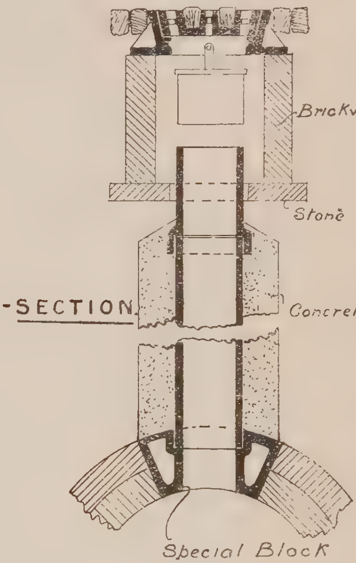


FIG. 165.

In fig. 170 is shown a manhole for use in passing through open country. The heavy cover is then replaced by a flagstone and the ventilation effected by a separate chamber and cover. In bad ground, the construction of brick or concrete manholes becomes an awkward job, to avoid which many engineers use special shafts formed of cast-iron segments. These are flanged and bolted together in the same way as cast-iron sewers. A taper piece is provided on the top, upon which rest a granite curb and an ordinary cover. The base segment has a base plate and two short lengths of either flanged or spigot-and-socket pipes, as the case may be; concrete trowelled off forms the invert of the sewer. They make a very neat job; one is shown on section in fig. 171. The same advantages are now obtained more cheaply by the use of concrete tubes, reinforced or not according to circumstances. They have rabbeted joints, and are easily put into position. In fig. 172 details are given of what is known as a "ramped" manhole, to connect sewers at different levels, so as to avoid the use of a tumbling bay, which is considered to cause the evolution of

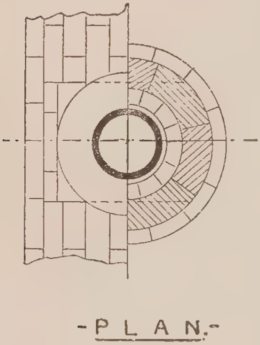


FIG. 166.

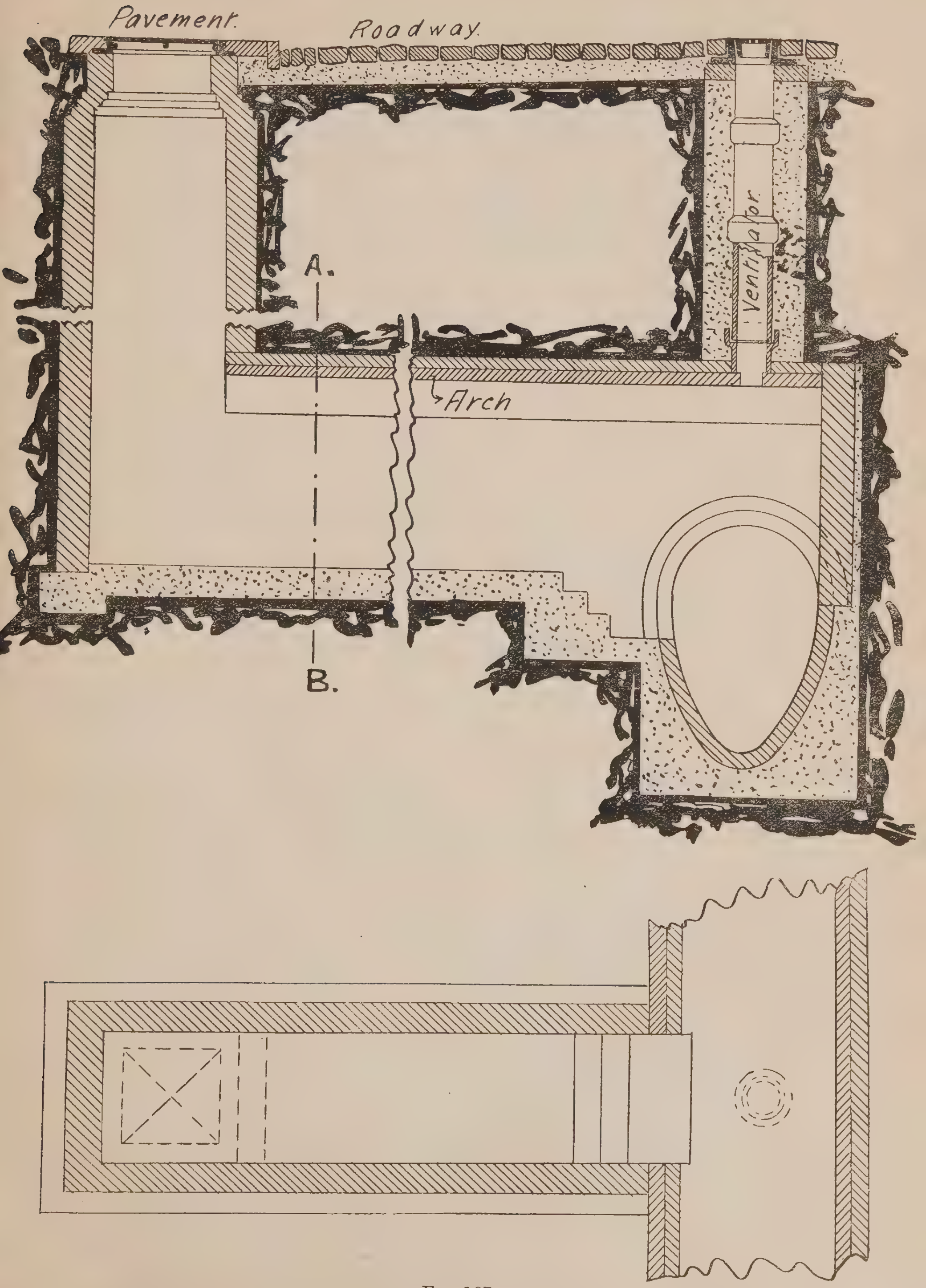


FIG. 167.

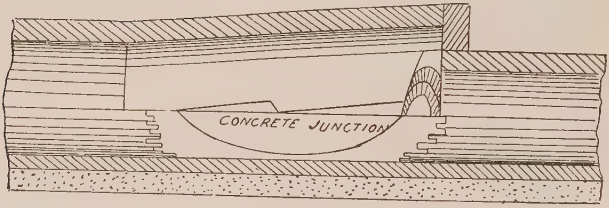


Fig. 168.

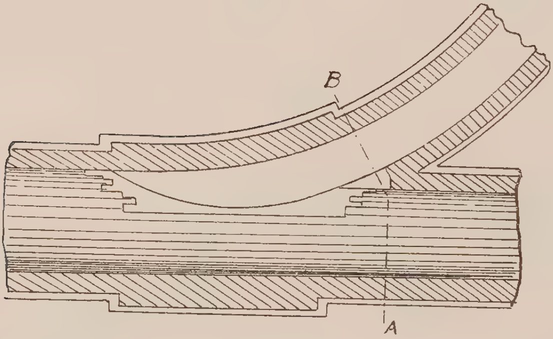
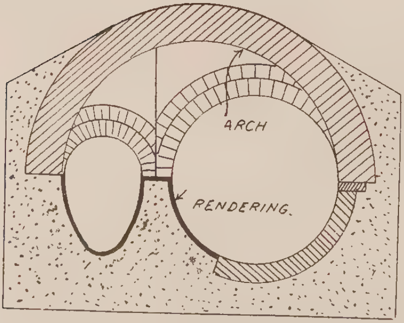


Fig. 169.



ENLARGED SECTION
A. B.

Fig. 169a.

sewer gas. The construction is quite simple, and the straight line is for inserting rods up the sewer and inspection. Or the work may be carried out as shown in fig. 173 if the sewers are at right angles. Ramps in sewers serve two purposes :

1. Reducing velocity.
2. Subdividing the drainage area into ventilating zones, which tends to reduce flooding in the lower parts, and the collection of foul gas in the upper ones.

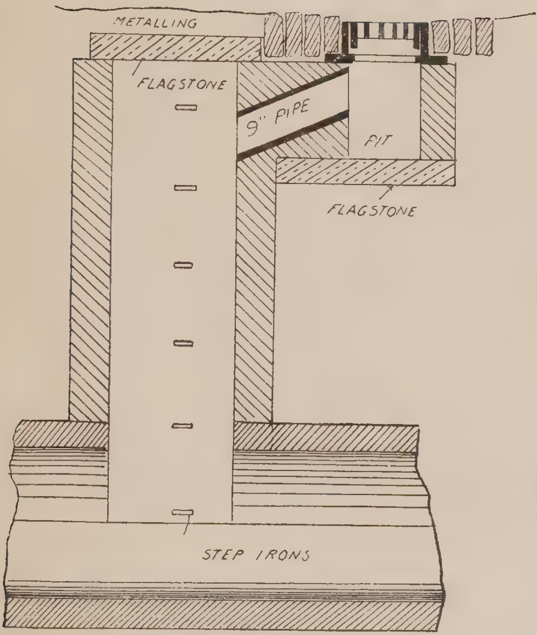


FIG. 170.

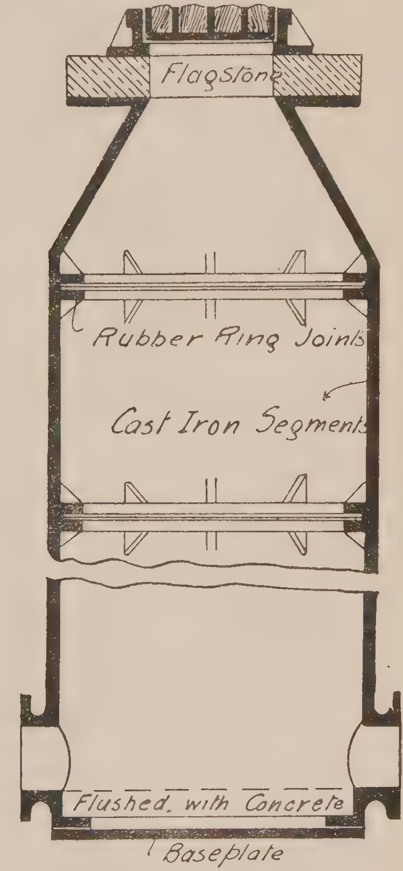


FIG. 171.

Wear is also reduced in the case of sewers with steep gradients, and bursts prevented. The incoming sewer of a ramp has a flap thereon. It need not be of heavy construction ; those made of aluminium are very often employed, and are preferable if made in three sections, each swinging on a horizontal axis. This ensures rapid response to the pressure exerted by even a small flood, and prevents backwater. A suitable manhole designed on this principle is shown in fig. 174.

Another system of connecting sewers at different levels when the drop is great, say over 8 ft., is shown by fig. 175. It is formed of cast-iron pipes, the junction piece usually being a special casting. Flanged or spigot-and-socket pipes may be used, but the former are preferable ; they must be securely fastened to the walls of the manhole by bolts passing right through the brickwork and attached to cast-iron plates on the far side. Immediately below the mouth of the pipe an invert is formed in the manhole of specially hard Stafford blue bricks, which will successfully reduce the wear set up by the continually falling liquid.

It is often desirable in manholes to have some means of stopping the flow from any of the branches. For this purpose an ordinary hand-stop plate is sometimes used, which simply consists of a casting bolted to the end of the branch pipe and having grooves for the cast-iron plate, which has four planed faces. It is not very satisfactory, because it is liable to get stuck fast, and the person who removes it is liable to get wet from the rush of water. A much better idea is the disc valve, of which a good form is made by Messrs Adams, as shown by fig. 176. It has properly fitted, scraped, water-tight faces, and can always be easily released by means of a lug shown on the handle, which, when this handle is pulled over and pulls the chain, slightly lifts the disc, and so gives it a start. Another contrivance for the purpose is the penstock, shown in figs. 177 and 178, which is raised by a screw and worm-wheel motion. The one shown is suited for use on an 18-in. pipe, but the design is capable of great modification, and very heavy gates of large dimensions, specially shaped for egg-shaped sewers, are now made. Some have balance weights, and

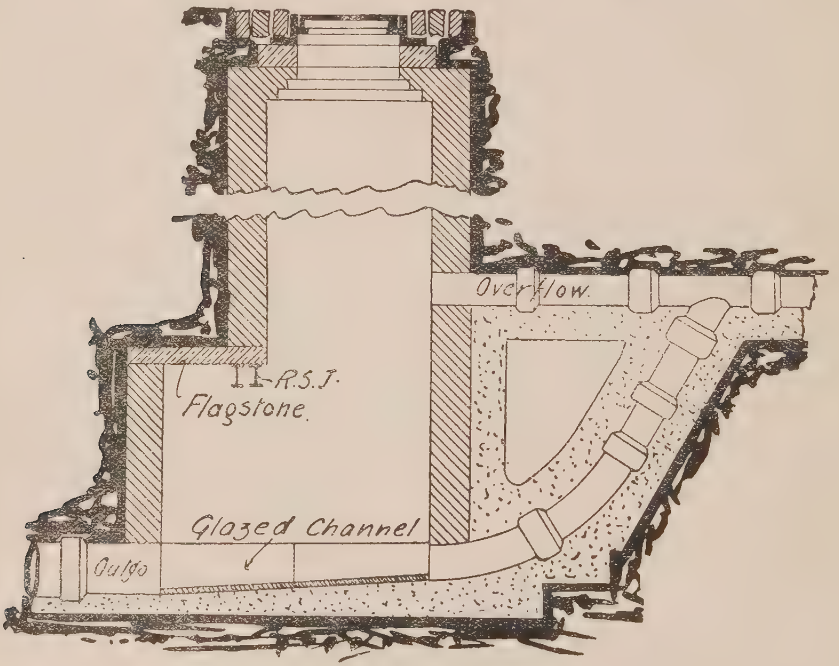


Fig. 172.

others bevel and worm gearing combined, which give any required mechanical advantage. Gun-metal faces, when provided, make a good job.

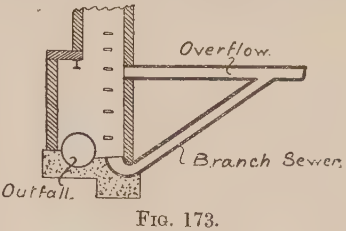


Fig. 173.

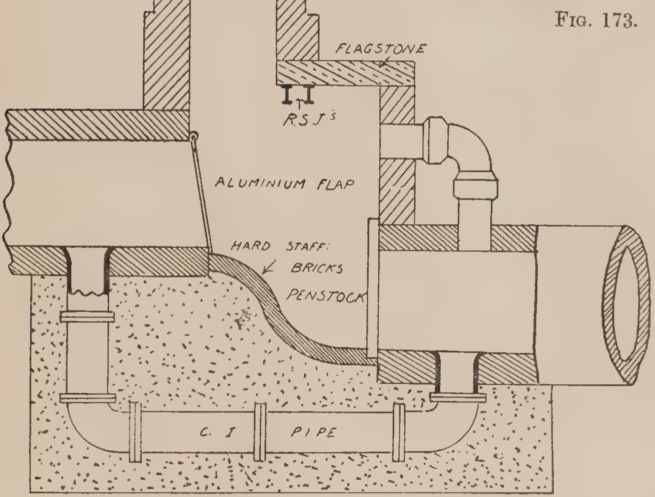


Fig. 174.

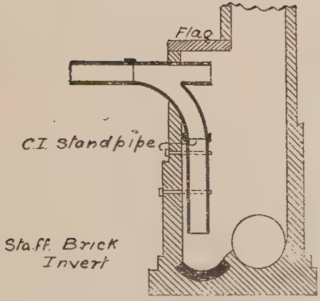


Fig. 175.

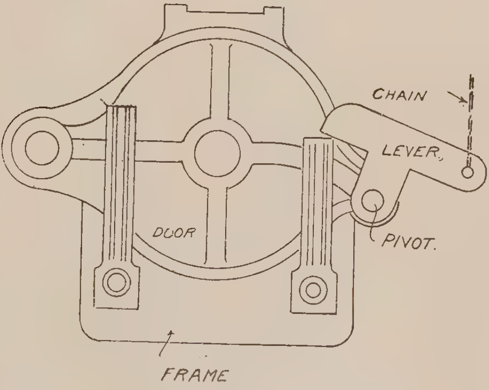


Fig. 176.

Another useful form of construction introduced by Messrs Ham Baker & Co., and illustrated in figs. 179 and 180, is known as Stilgoe's manhole.

Stilgoe's patent cast-iron manhole invert enables engineers to construct manholes on a line of sewer while water is running through the pipes, thus saving the expense of pumping.

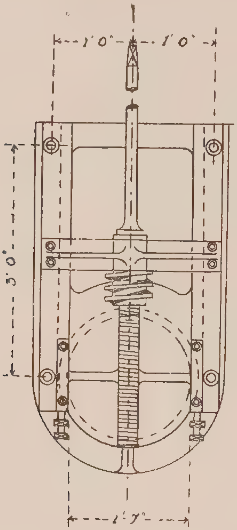


Fig. 177.

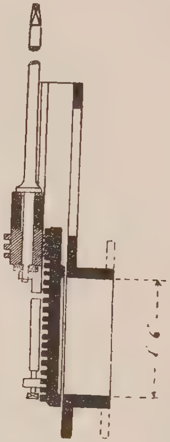


Fig. 178.

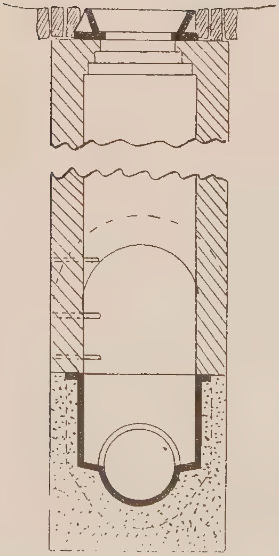


Fig. 179.

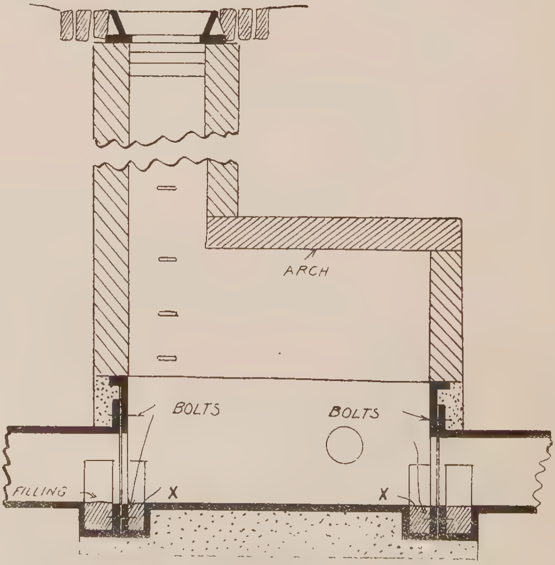


Fig. 180.

The sewer may be laid with cast-iron pipes having turned and bored joints, or stoneware pipes with patent joints for ensuring watertight work.

These inverts for manholes, as shown in the illustrations, are made in one casting with inside flanges for connecting up to the first pipe on each end of the manhole, and also with any side branches required (one of which is shown in fig. 180).

The pipes up to the manhole having been laid, the invert casting is lowered into position. A rubber ring or other suitable jointing material is placed between the internal flanges on the pipe and the invert casting ; the two are bolted together, and the joint made in the same manner as the flanged joints of a water main.

A very important item is the construction of the pockets on the end of the pipes, also on the invert casting, as shown and marked on the diagrams. This enables the bolts to be inserted and tightened up by a man standing inside the invert casting while the water is running through. After the joints are made, the pockets are filled up with cement and left all flush.

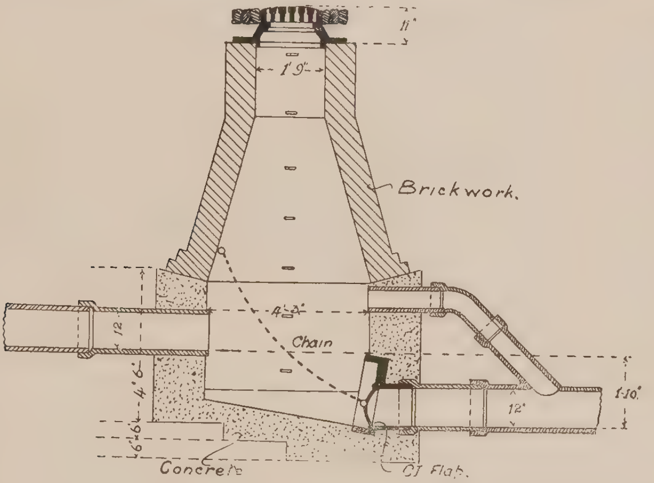


FIG. 181.

The invert castings are made to any height, according to the depth of the subsoil water anticipated, and can be bedded in concrete or not as desired.

Side branches can be provided on invert casting of any size, position, or angle desired.

This arrangement was successfully used in the reconstruction of the Dover sewers and the work carried on without pumping, notwithstanding the fact that the pipes were covered by running water all the time. The sizes of the inverts there used were 5 ft. long × 3 ft. wide on the 24-in. diameter sewers, and 5 ft. long × 2 ft. 6 in. wide on the smaller ones.

Flushing.—Sewers which have not a self-cleansing velocity may be kept free from risk of obstruction by flushing. A sewer which has a velocity below 2 ft. per second cannot be said to be self-cleansing. That a sewer has a slow rate of flow is not necessarily the result of indifferent engineering ; the top end of a sewer may have very little flowing into it, and yet it may be inadvisable, in order to get a self-cleansing velocity, to make it smaller. Again, the general fall of the district may be very flat. It is principally for the former reason that flush tanks are provided at the head of a line of sewer, but they are necessary on a sewer which has a sharp fall, and yet has not a large flow of water in it, because in dry weather solids are left behind in the pipe, due to house w.c. flushing cisterns being very small (about 3 gallons capacity usually). Again, new sewerage is generally laid down in partially developed districts, and the sewers, not being worked at their full capacity, require artificial flushing.

Various means are employed for the purpose. The valves referred to may be used to effect it, but they are not automatic, and require attention every time the sewer is flushed. For occasional flushing, the manhole and valve shown in fig. 181 may be employed with advantage. It simply consists of an ordinary cast-iron flap valve placed on the outgoing sewer of any manhole, and normally held up by the chain shown, and it is let down on to its seat when flushing is desired. The sewage will then back up to any desired height in the manhole until the valve is drawn up by the chain. The only necessary addition is the overflow pipe of half (or more) the capacity of the incoming sewer. Another system for use in a larger sewer is that shown by fig. 182, which aims at closing back the sewage by means of a gate of cast-iron (known as a half or three-quarter gate according to its size), opened and closed by hand. Sometimes in a manhole chamber the incoming sewer is directed into a tipping trough, which, when full,

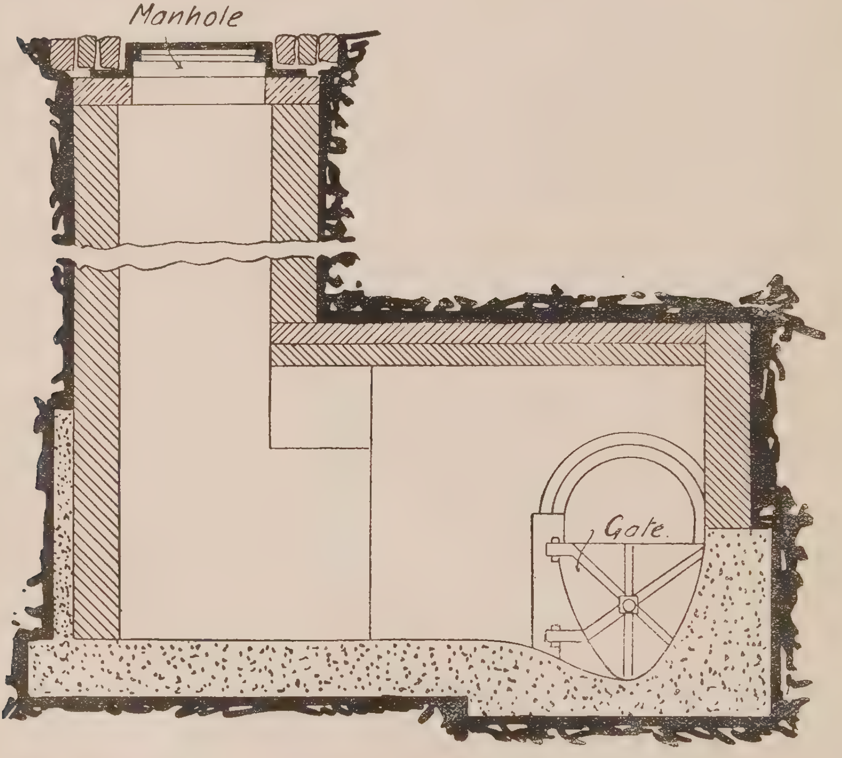


FIG. 182.

overturns on trunnions about a horizontal axis, delivers its capacity of liquid instantaneously, and then returns to its normal condition. In the writer's opinion they are not of much use. By far the most usual way is to form a watertight chamber at the head of a sewer of large capacity, which has a supply of water laid on, and when full automatically discharges its whole volume in a very short space of time. This is effected by what is termed a syphon.

The use of a syphon is not absolutely necessary; it may be that the water is simply let off by a hand-stop valve, as shown by fig. 183. The

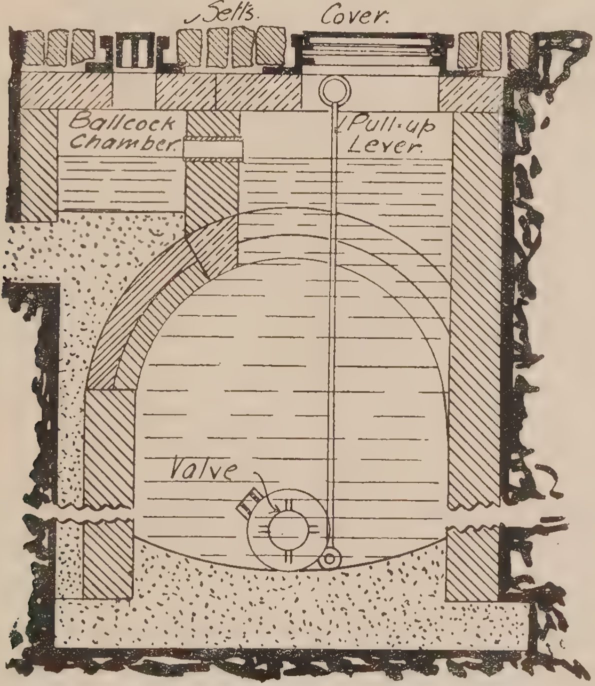


FIG. 183.

capacity of flushing tanks is settled by the designer; 1000-2000 gallons, according to the size of sewer, would be a good size. In figs. 184 and 185 is shown an ordinary form of flushing tank. It consists essentially of a large brick or concrete chamber, into which water or sewage flows. In this chamber is placed a cast-iron syphon and discharge pipe. As the water rises, so the air is discharged from the bell. A dribbling then takes place, which finally exhausts all the air, when the pressure of the atmosphere causes the contents of the whole tank to be suddenly discharged at considerable velocity. The action is similar to the ordinary w.c. cistern, only the pull of the handle actuates the cistern, while the flushing-tank syphon is automatic. By lifting the bell, however, it can be made to act at any time. The tank shown was designed for taking sewage. A screen is provided so as to prevent foreign bodies from choking the syphon. An overflow must always be provided, too, in case of failure of action. The refuse which collects at the bottom of the side chamber may be let off periodically by the plug valve. It is preferably done before a flush is sent down. To make a syphon discharge effective, the length of the shorter leg of the syphon must be equal in length to the depth of water above the bell at the level it is required to start discharging. For very large sewers, however, flushing tanks, in order to have any practical effect, would have to be so large that they usually give way to the use of flushing gates. A flushing tank for use with fresh water is shown in fig. 186; but the syphon is of a different kind to the previous one, and is known as the Roger's Field Syphon, and its construction, which is very simple, is clearly shown; while a third type in use is the Adams-Millar Syphon, shown in fig. 187, consisting of a discharging limb or deep seal trap, the discharge mouth at the outlet, and the intaking limb or bell, which is placed over the longer leg of the syphon and held securely in place by its own weight.

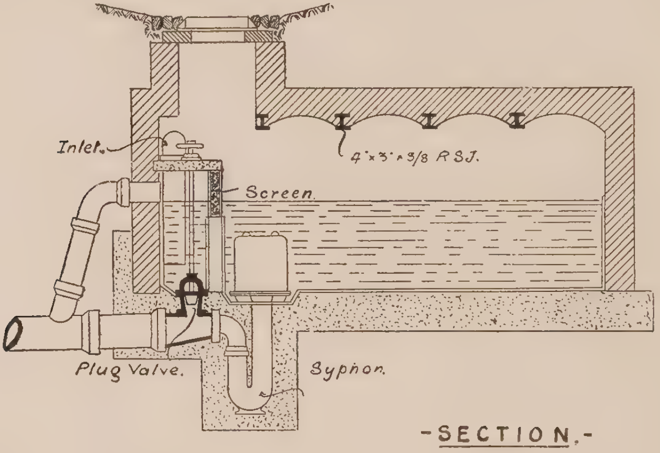


FIG. 184.

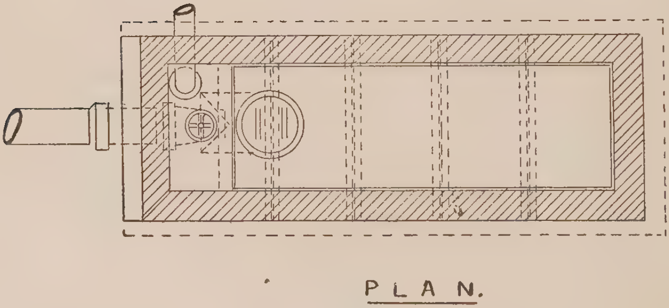


FIG. 185.

The top end of a sewer may often be very shallow, and the flushing tank may not have enough depth to take any ordinary syphon of the type already described. In any case, the velocity of discharge from any particular syphon is a quantity dependent upon the depth of water on the syphon, and for shallow depths the outlet area has to be increased, which has given

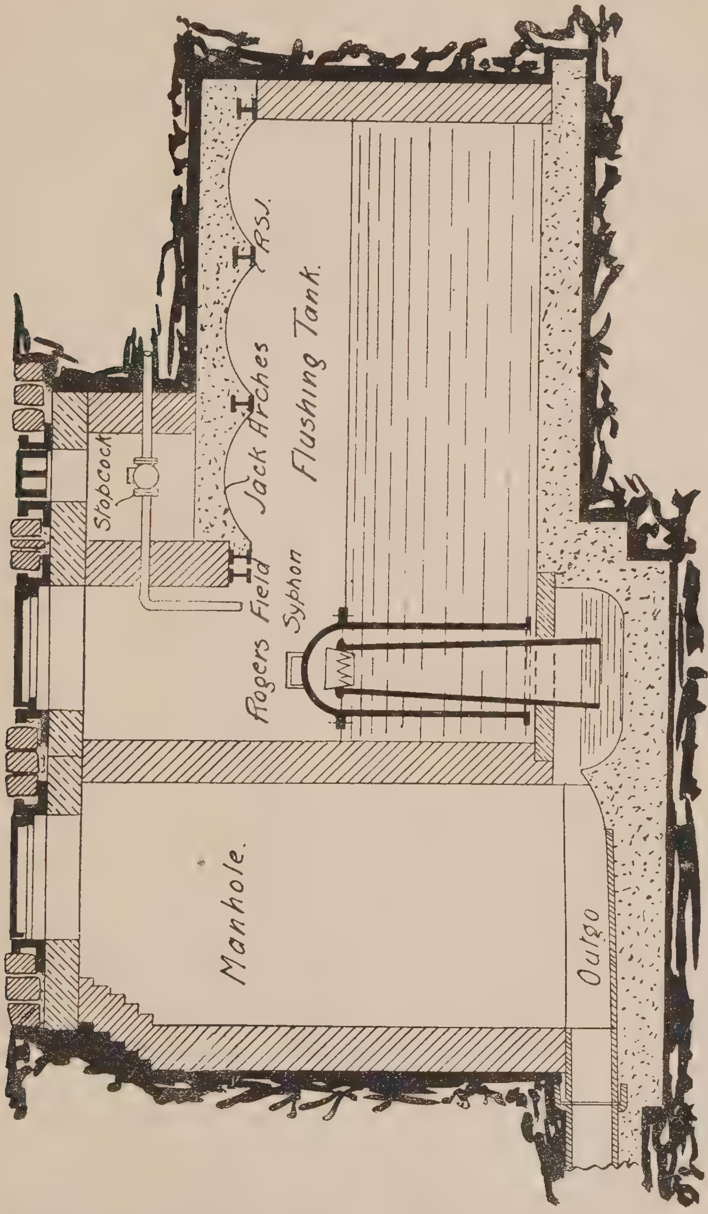


Fig. 186.

rise to the design of the low-draft syphon shown in figs. 188 and 188A, made by Adams, which will work from a depth of 6 in. In all systems of flushing tanks there will be a certain point on the sewer where the discharge will

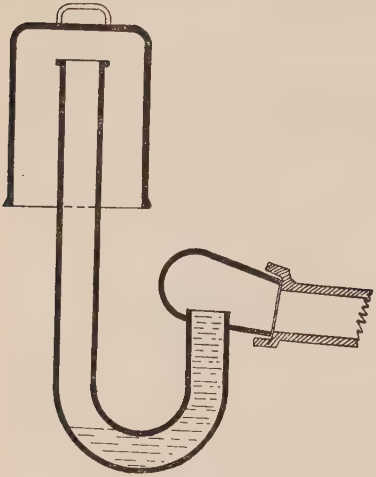


FIG. 187.

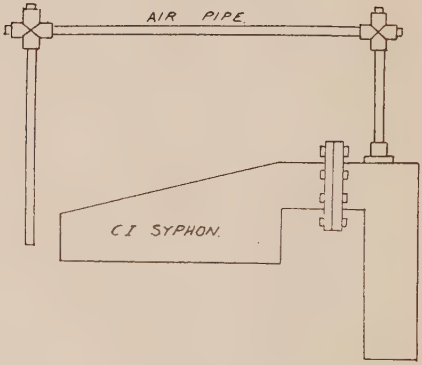


FIG. 188.

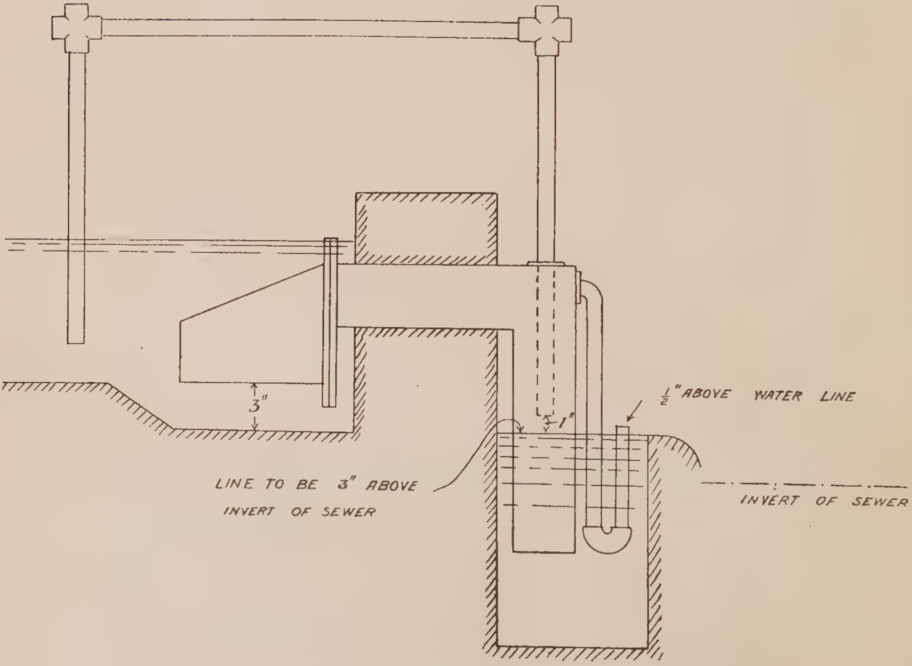


FIG. 188A.

cease to have any effect and the velocity will be normal. The distance flushed is not a very important consideration, but information on the question is given in Mr S. H. Adams' sewer-flushing diagrams.

The use of flushing tanks is not to be advised on tide-locked sewers, as the effect of the flush is soon nullified, and flushing gates of the types shown are generally employed for the purpose.

Sea Outfalls.—Regarding tidal outfalls, reference has already been made to forms of sewers suitable for conducting sewage to low water. But at the junction of such sewers with the main intercepting sewers a special form of manhole chamber is usually built, the purpose of which is to control the flood water, and to assist in ventilation and inspection. A manhole of this description, which might be placed in the sea-wall of a seaside town or river-wall of a small town on a tidal estuary, is shown by fig. 189. It could also be modified to suit a town built on cliffs, by carrying the sewage down to low level by means of cast-iron pipes in a masonry shaft, terminating in a rest bend, well supported at the base; while the ordinary sewer would be extended to the face of the cliff in cases of emergency, or, better still, the shaft in which the cast-iron pipes run may serve this purpose, being otherwise dry and accessible to workmen for inspection of the cast-iron pipes. In any case the lower part of the main outfall sewer should be formed extra large, in the shape of what is known as a tank sewer, to provide a certain amount of storage room during flood tides, and it would be proportioned accordingly, so as to hold up the required quantity. A good form of tank sewer is shown by fig. 190. It consists of a chamber provided with a tidal flap, a penstock of the form shown in figs. 177 and 178, and two draw weirs, consisting of slots in the masonry, for the introduction of boards to shut off either end entirely, for repairs, etc., to the valves. Another form of tank sewer with side inlet manhole is shown in fig. 191, while an outlet into a flat tidal estuary of special construction is shown in figs. 192, 193, and 194.

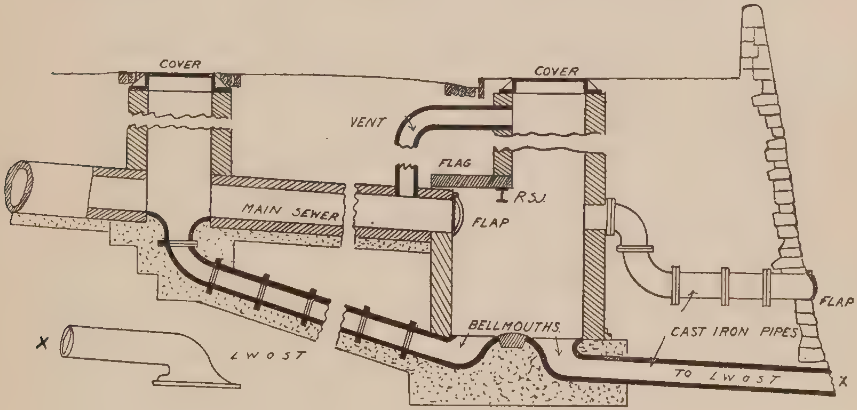


FIG. 189.

Gates of this sort are specially suitable for large volumes of water, especially when well diluted. They find use in land-drainage schemes very

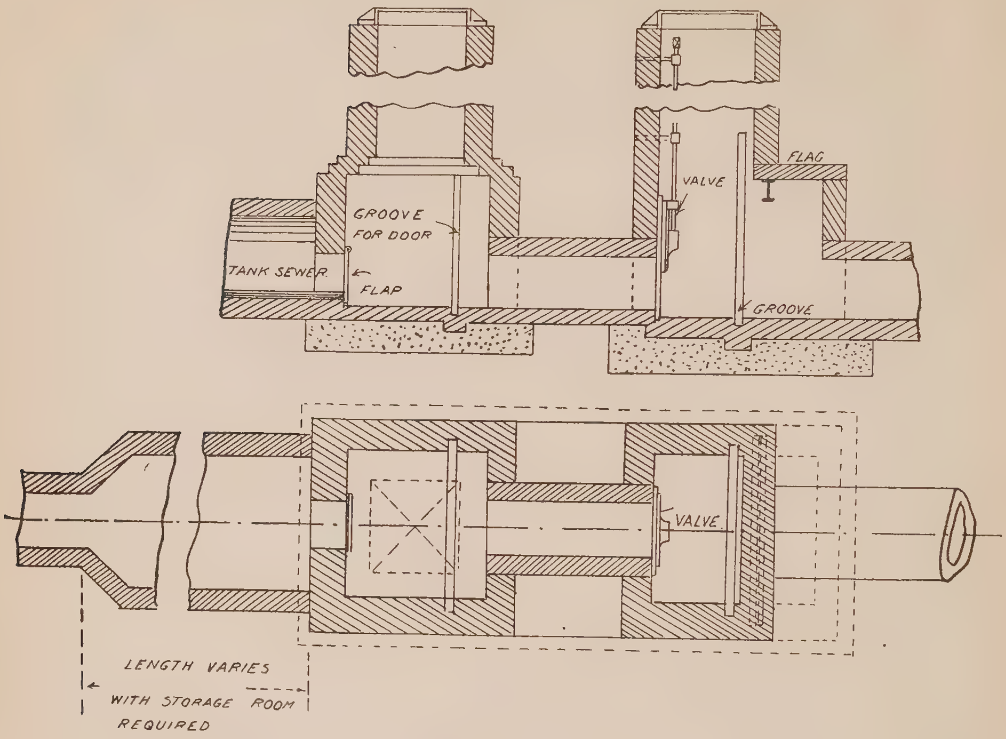


Fig. 190.

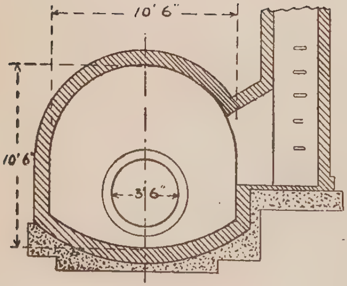


Fig. 191.

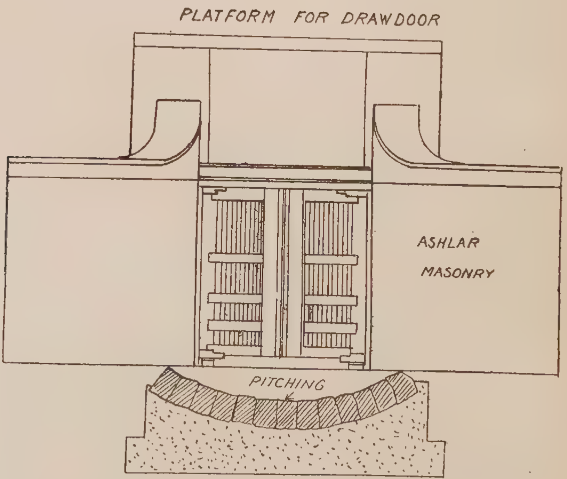


Fig. 192.

often. The doors shut against a solid wooden sill at the bottom and a pointed wooden frame at the top. The piers must be capable of withstanding the strain transmitted through the gates by the pressure of a head of water on the outside, the doors meeting at an angle of about 125°. The heel-post works in a pivot at the bottom, and is held in place by an anchor strap of wrought iron at the top. On the inner side draw doors are provided, working in grooves; a special crab gear is very useful for raising them. Many other forms of outfall could be designed to suit certain circumstances; ideas will always present themselves to the intelligent reader.

Gullies and Catchpits.—In connection with any main-drainage scheme it is usual to provide for removing water from the streets into the sewers. Wherever it is possible, such water should be conducted into the nearest watercourse or to some land drain and there disposed of. In Chapter III. this was advised, because the total volume of sewage to be treated at the outfall works is reduced accordingly. The disadvantage of providing separate drains for such water has been pointed out, at the same time showing that where this was not done the sewers must be capable of taking a large amount of the surface water and road washings. Road washings, being often very foul, should by rights go into the sewers, but the solid matter contained in them, being principally sandy matter and horse-droppings, is naturally heavy, and the advantage of intercepting such matter before it gets into the sewers is apparent to all, bearing in mind that sand and silt tend to cause an obstruction in a sewer more than anything else, and also give trouble at the purification works. Hence resort is made to some form of box or trough into which some of the solid matter will be deposited, and is known as a "gully trap." Small gullies find use in house drainage for purposes which will be pointed out in a later chapter. The purpose of the road gully is to remove surface water, intercept silt, and trap off the sewer air. Regarding this latter consideration, it was at one time considered to be an advantage to allow the water to pass direct down a pipe into the sewer, which pipe acted as a ventilator thereto. The disadvantage of this was pointed out in the previous chapter. As

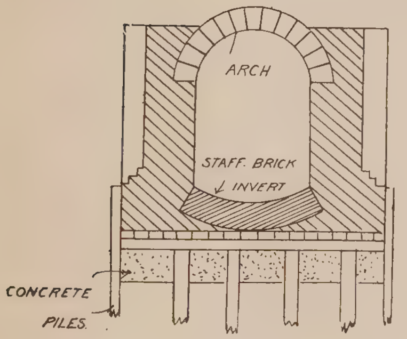


FIG. 193.

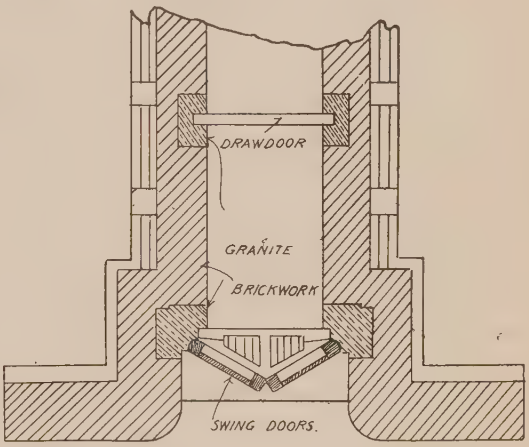


FIG. 194.

regards the first consideration, the gully should be so designed that the maximum facility is afforded for the entry of heavy and rapid rainstorms; and as regards the second, rapid and easy removal of the detritus should be provided for, with the minimum risk of nuisance to the public. Strength being a necessity, cast iron is generally used for road gullies. A common form is shown in fig. 195. Access for cleaning is gained by lifting out the top bell-shaped casting. So far as it goes the construction is sound, but as the seal is shallow, dry weather may easily evaporate the water and lower the water-level below the lip; the trap would then cease to exist, necessitating attention by the water-cart men; in fact, many towns have special water-carts for the purpose. This difficulty is, to a certain extent, overcome by the use of the double-seal gully shown in fig. 196, made by Messrs Ham Baker & Co.

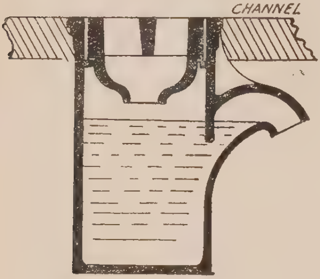


FIG. 195.

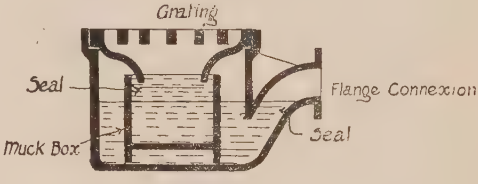


FIG. 196.

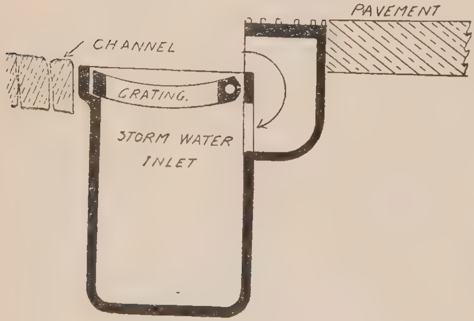


FIG. 197.

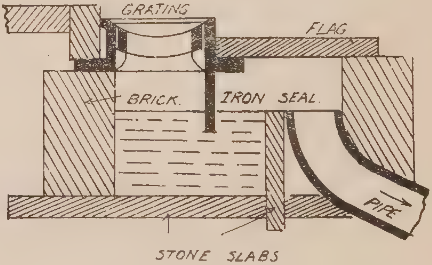


FIG. 198.

Many engineers have designed gullies to suit their own particular requirements. One of the most practical yet brought under the writer's notice is that invented by Mr T. W. Brown, M.I.C.E., who required them for use in the borough of Hartlepool. It is made by Messrs Adams & Co., who claim for it that it has an ample trap, means of readily inspecting the drain, and a large storage capacity; but the strong point in its favour is the special storm weir (shown in fig. 197), so that, in the event of chokage of the grating or an excessive flow, the overflow comes into operation and

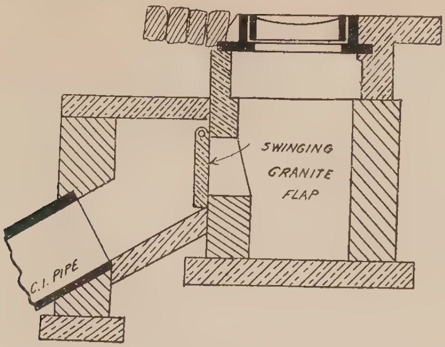


FIG. 199.

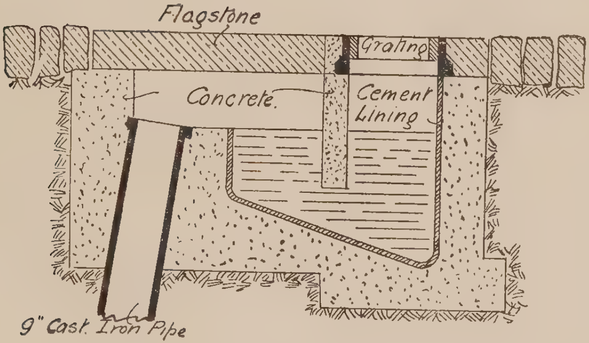


FIG. 200.—Built Gully Pit.

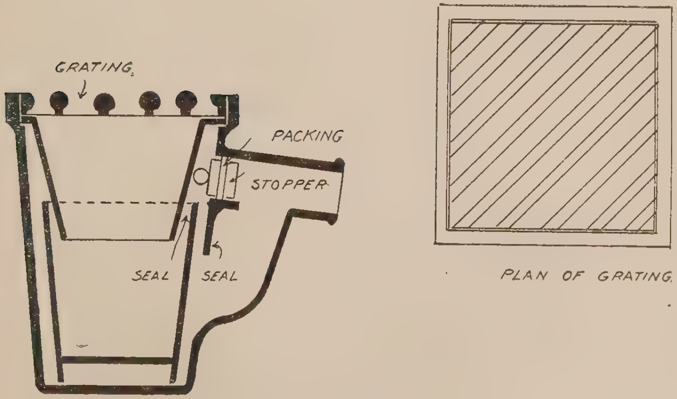


FIG. 201.

prevents the possibility of the roadway being flooded, which is a frequent occurrence with ordinary gullies and a great nuisance. There are many surveyors, however, who like the built gully, or rather cesspit, made of concrete or brickwork, and having a specially heavy cast-iron grating on the top. An ordinary form is shown in fig. 198, built of 9-in. brickwork, set in cement mortar: while one in which the seal is effected by a hinged flap valve is shown in fig. 199; and a favourite form with the writer is given in fig. 200. In hilly districts special care must be taken to effect a rapid removal of the water; in some traps provision is made for this by specially shaped grating bars, shown in fig. 201; and one designed for the purpose by the writer and formed in concrete is shown in fig. 202, in which ordinary flows pass down the single slot, while the grating supplied is for intercepting any which will leap over this during heavy rains. The grating is hinged for cleaning. A very large storage-room is provided for detritus.

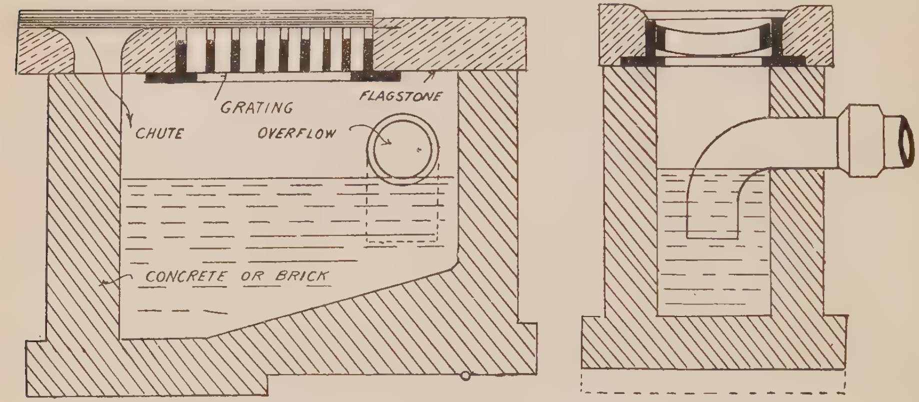


Fig. 202.

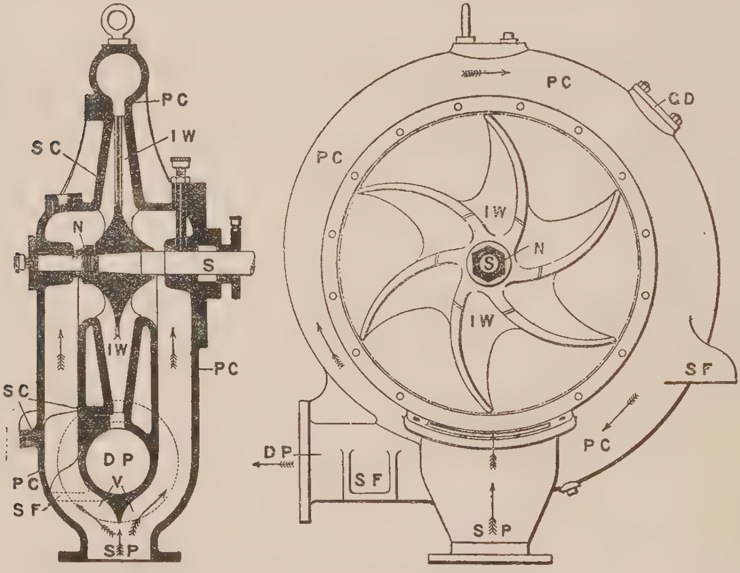
CHAPTER VIII.

PUMPING SEWAGE.

Whether part or whole of a town's sewage has to be raised is a matter which depends on many circumstances. It has already been pointed out that the best outfall is not always at the lowest part of the town, and also that land for the outfall works may be unattainable or too expensive at that point. Both these circumstances demand that part of the sewage must be raised, while in many towns it is wholly raised. In the borough of Salford part of the sewage flows by gravity into the tanks and part is lifted; while in Dublin, under the new main-drainage scheme, the whole of the city sewage which flows by gravity to the Ringsend power-station is there pumped up and flows onwards by gravitation to the purification works at the Pigeon House. In designing a scheme for any particular town, when pumping is likely to enter into the question, the matter demands the most minute and expert consideration, because no hard-and-fast rules can be laid down. First of all is the quantity of sewage to be raised. A gallon of sewage weighs 10 lb. (roughly), and there are 33,000 ft.-lb. in 1 horse-power; consequently 3300 gals. raised 1 foot in one minute constitute a theoretical horse-power, and probably $1\frac{1}{2}$ actual horse-power. It is only under favourable circumstances that 5 horse-power per hour can be obtained for 1d. On this basis the engineer can form a tolerably accurate idea of the cost of fuel; to which, of course, must be added depreciation, repairs, oil, stores, wages, etc. Again, the cost of the plant and the amount of sinking fund which it entails must be taken into account. A reliable estimate may then be formed as to whether pumping certain sewage is advisable. Of course, some places have to put down plant at any cost in order to get rid of the sewage; then it is simply a matter of the best plant to install.

Centrifugal Pumps.—First and foremost amongst the various appliances for raising sewage is the centrifugal pump, because the volume of liquid to be raised is usually large and the height to which it has to be pumped small in comparison, for instance, with waterworks which usually employ some form of plunger pump. Centrifugal pumps are very simple in construction, strong, low in first cost, and easily and cheaply put down. Moreover, a well-designed and constructed centrifugal pump will raise a larger quantity of water for a given power than any other pump when the circumstances are suited to its adoption. Again, the absence of valves, beyond the foot valve, allows of its passing gravel, sand, leaves, etc., which would choke ordinary pumps.

The working parts of the pump consist of a series of curved blades mounted on a spindle and revolving in a cast-iron case. When once the casing is filled with water and the blades begin to revolve, centrifugal action causes the water to flow along the blades from the centre outwards. Thus it will accumulate pressure in the volute chamber, according to the speed and design of the pump, which pressure causes the liquid to rise in the discharge pipe. The simplest form of centrifugal pump is shown in figs. 203 and 204. Each part is named so that the drawing is quite self-explanatory. While the reader is not concerned here with the design of pumps, it is desirable that he should understand fully the essential features of those types which are used in sewage pumping. The principal point in the design is the blades, which in high-class pumps are properly proportioned and arranged according to the duty which the pump is required to perform. To ensure efficiency they must be so arranged that the water will enter the pump without more shock or friction than necessary. The form of blade which appears to have been most useful in this direction is the type which is curved and fixed almost tangentially to the periphery of the pump disc. In badly designed pumps, or in those which are not designed for the particular duty they have to perform, much loss of power will result from unnecessary fluid friction, as this causes uneven flow at delivery and eddies in the pump. The pump illustrated has a double suction, but others have the suction on one side only. This induces a lateral thrust, which is counteracted by a thrust block, or avoided by removing the centre of the pump disc. For sewage pumping it is a wise plan to employ the simplest kind of pump that is efficient. There are many ingenious improvements in centrifugal pumps on the market, which



FIGS. 203 and 204.—Centrifugal Pump.

SF, supporting flanges; PC, pump casing; CD, pump door; SP, suction pipe; V, suction water guide; IW, impeller wheel; S, impeller shaft; N, impeller nut; DP, delivery pipe; SC, side cover; »—→, direction of flow.

may have all the advantages claimed for them; but, in the writer's opinion, they are well avoided in this connection. The foundation plate for the pump should be cast in one piece with the standard for the bearings, and the casing should be so arranged that one side may be taken off for inspection and cleaning, and hand holes in the suction pipe for the same purpose. The principal duty of the engineer who has sewage pumping plant to put down is the decision of the class of pump to be employed. Except in very small works, it will rarely be found that any other pump offers the same advantages as the centrifugal. An estimate should be got from reputable firms for a pump suited to the duty. In order that the firms may do justice to themselves, the greatest care should be taken to give full and accurate particulars, because the speed at which the impeller rotates bears a fixed relation to the total head produced by the pump. Any change from the normal designed speed of that pump will result in a variation of the head as the square of the speed, and variation of the quantity discharged as the number of revolutions; hence the necessity of accurate data being furnished. Especially is this so in the case of electric driving; in fact, with the use of three-phase motors of a constant speed, a slight error in the head may produce failure of the pump at once. With displacement pumps the head is practically constant at all speeds; an obstruction in the discharge pipe would probably wreck it. Hence the centrifugal pump allows percentage of overload, because the pressure will not materially increase, while the velocity will; but at the same time each pump must have its overload capacity clearly stated by the makers, otherwise the effect of overloading may be serious. Other points in favour of the centrifugal pump are:

1. The first cost is less than a high-class displacement pump of a similar duty.
2. The floor space is usually about one-third.
3. The convenience of operation is apparent to all, and the absence of any parts to get out of order or to demand the constant employment in small works of skilled mechanics.
4. The pumps are free from noise. This is important, as small separate units, electrically driven, can be placed in districts where other machinery would not be tolerated by the residents, to say nothing of the possibility of placing such units in all sorts of out-of-the-way places, where they will work with the minimum of attention.

The casings of centrifugal pumps are usually made of cast iron, as also are the bed plate, covers, suction and delivery branches, etc. The shaft is of steel and the impeller of cast iron, machined, polished, and balanced. It is quite possible, if deemed necessary, owing to any special impurities in the liquid to be pumped, to make the impeller and shaft of manganese bronze or stainless steel. The impeller is secured to the shaft by feathers on itself and lock nuts.

The bearings should be of the ring-oiled type, and entirely separate in the latest types from the stuffing-boxes. This is essential with sewage pumping, because it prevents grit finding its way into the bearings, and allows of perfect lubrication for high-speed running.

In figs. 205–207 is illustrated a good example of a low-lift centrifugal pump by Messrs Allen & Co., Queen's Engineering Works, Bedford. It is driven by a high-speed compound engine, and the plant consists of two pumps side by side, but each capable of being disconnected if required. The figure shows all the details of a well-arranged plant, and attention is directed to two points—that is, the gauge glass and what the makers call the "credenda" pipe. The former is a simple gauge glass in the pump casing, to allow of it being seen if it is full of liquid when ready to start up and during work. It is quite essential to have the pump full before starting the engine. For this purpose the older pumps employed a foot valve in the suction pipe quite similar to those used in reciprocating pumps. In this case, however, which is the best practice with steam plants, this is done away with and the credenda pipes substituted. They connect with a very simple ejector on the top of the pump casing. The admission of steam to this ejector causes a vacuum in the pump, and the liquid consequently rises in it. When the pump is started the ejector is put out of action.

It may here be stated that the lift to a centrifugal pump should not exceed 7 ft.; in fact, so very much latitude is allowable in the erection of these pumps that it may be possible to allow of the pump having a gravity suction, which is a good practice. An electrically driven plant by Allen & Co. is shown in figs. 208–212, in which a simple charging funnel is used for connection to some supply or another. Otherwise the details are very similar. A foot valve is, of course, required on all pumps which have no ejectors. The pumps in question, like all others, are erected on concrete foundations. It is the duty of the engineer to see to the putting down of such. When the pumps are put in hand, the maker will supply prints of the size and shape of the foundations, and the measurements thereon must be rigidly adhered to. Concrete in the usual proportions adopted is the most suitable material. The excavation for them need only go down to hard compact subsoil whose bearing capacity is known. It is wise not to load up to a greater intensity than 1 ton per square foot, and this is usually possible.

It may be, however, that the ground is very soft, and that a piled foundation will have to be formed, or a raft foundation of reinforced concrete. These are matters to which the reader's attention must be drawn, but their discussion would be out of place here. The concrete should be placed in moulds constructed to the sizes shown in the drawings, and raised to within 1 in. of the required level. It should then be left for twenty-four hours, after which 1 in. of 1 to 1 sand and Portland cement is floated on to top-level. The whole must then be left for at least eight days to set, and covered with wet sacks. When the plant is laid down on these foundations, the bed-plates should be lined up by means of wedges. After which the pump and engine (or motor) are placed on the facing strips and lined up in such a manner that the faces of the pump coupling are exactly parallel, and so that the pump and motor will run freely with and without coupling bolts in position. The bed-plate is then grouted in place so that it is absolutely rigid. The suction and discharge pipes are not placed in position till the foundation bolts are permanently set. The usual form of foundation bolt is shown in fig. 213. When the excavation proves wet, it should be carried down somewhat further than required, and then filled up to the water-level with dry stone or broken brick.

The suction pipes should be tested to see that they are perfectly air-tight. They should be as short and straight as possible, without air-pockets or unnecessary bends, or bends of other than a large sweep, a continuous rise, evenly distributed throughout, being given to the pipe. The foot valve should be placed well below the *lowest* level of the liquid to be pumped, and be of the double-flap type (fig. 214), with ample excess of area over the suction pipe, while the area of openings in the straining-rose must be *twice* that of the suction pipe; 20 ft. is the outside limit of suction for centrifugal pumps.

The increasing use of electricity for the operation of centrifugal sewage pumps has considerably extended the use of vertical shaft units. When conditions dictate that the pumps shall be located in an underground chamber, the vertical shaft pump is particularly useful, as it permits of the motors being suitably housed at or near ground-level. Neither vertical spindle pumps nor motors call for any special comment beyond the fact that the weight of the pump and its shaft has to be supported by a thrust bearing. In the arrangement illustrated in fig. 215, which may be taken as typical of modern practice, this is provided for by the ball bearing shown. In other cases a small Michell bearing functions very well. Two other developments in connection with sewage pumping may be mentioned—that is, the Stereophagus Pump and the Gwynne-Pennel Rotary Trap. The former has a peculiarly shaped impeller, and by means of a suitably arranged cutter solid matter is broken up before it reaches the impeller. It is, in fact, wrong to assume that the ordinary centrifugal pump will handle unharmed anything and everything that constitutes sewage, and this type of pump certainly warrants consideration. The Gwynne-Pennel Trap is rather an ingenious arrangement which intercepts heavy solids and by-passes them around the pump.

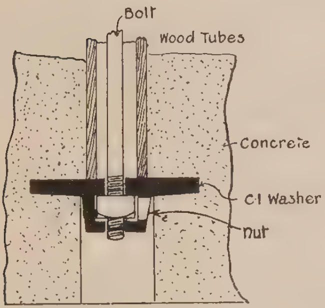


FIG. 213.

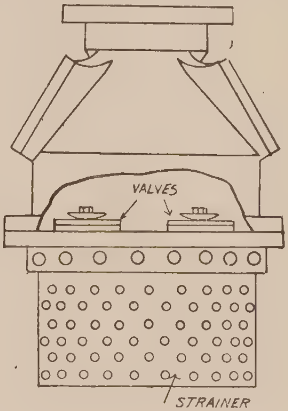


FIG. 214.

Reciprocating Pumps.—In waterworks this class of pump plays a very large part; they often reach large dimensions, and are built up on very expensive and high-class lines. In sewage works, on the other hand, it is not often found. The reason is that the centrifugal pump has so many paramount advantages as already set forth, and the height to which the sewage has to be pumped is usually within the limits of a well-designed

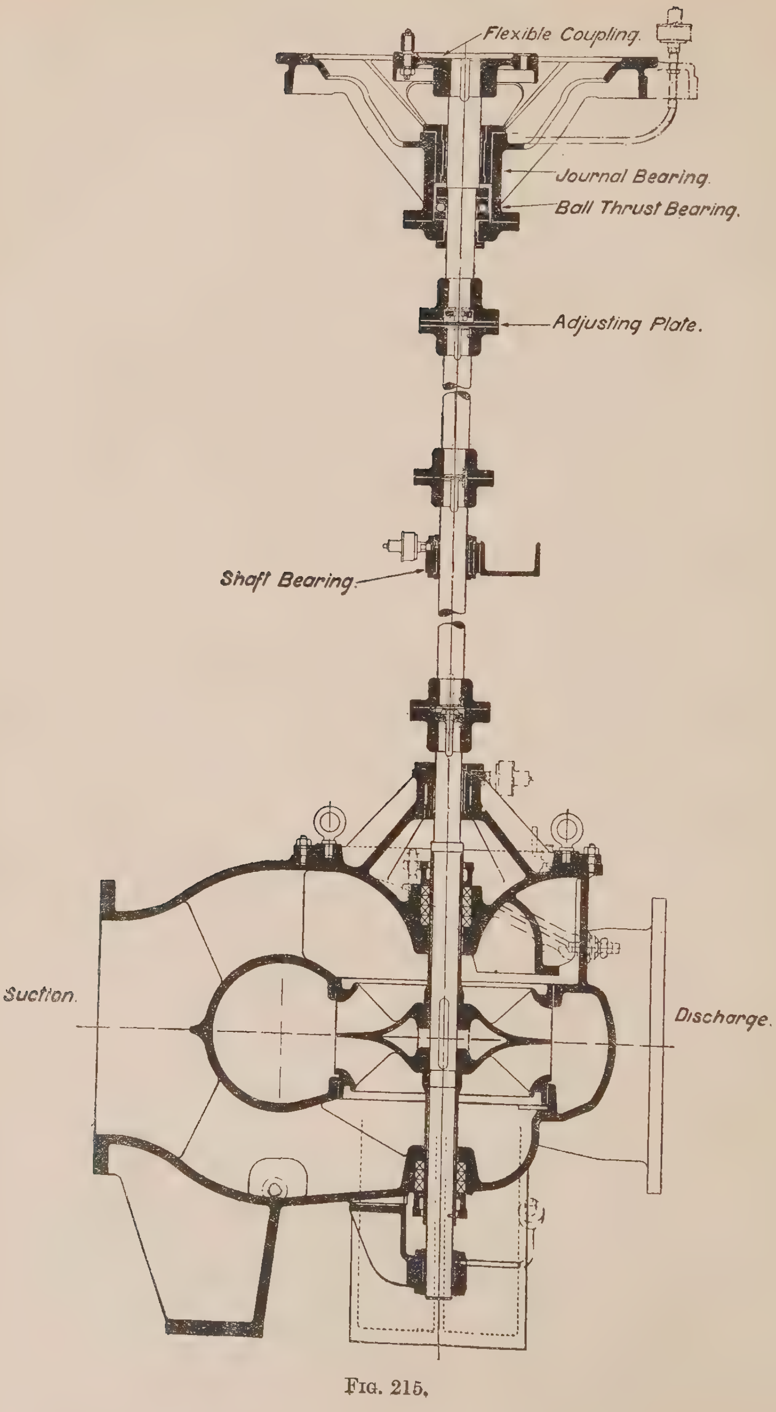
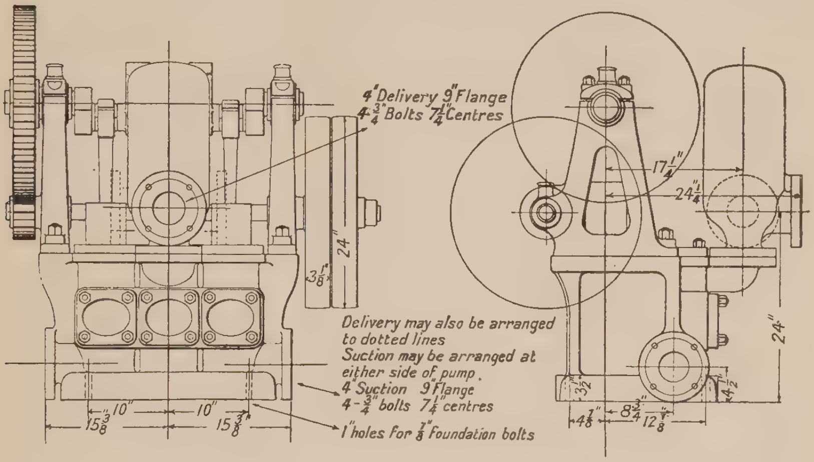
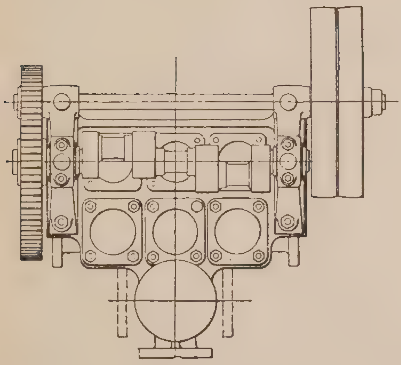

Flexible Coupling.
Journal Bearing.
Ball Thrust Bearing.
Adjusting Plate.
Shaft Bearing.
Suction.
Discharge.

FIG. 215.

single-stage centrifugal pump. For the benefit of the reader, however, the class of pump most suited for the purpose will be considered.

This pump is simple, and not easily put out of order. It will pass moderately heavy liquids, such as sewage, in a crude state. It is popularly known as the three-throw pump, or treble-ram pump; and although it may be in the form of a single or double ram, yet the three-ram type is strongly advised, owing to its more even working, which sets up less strain on the engine and less shock in the rising main.


4" Delivery 9" Flange
4-3/4" Bolts 7 1/4" Centres
24"
3 1/8"
Delivery may also be arranged to dotted lines
Suction may be arranged at either side of pump.
4" Suction 9" Flange
4-3/4" bolts 7 1/4" centres
1" holes for 7/8" Foundation bolts
10"
10"
15 3/8"
15 3/8"
17 1/4"
24 1/4"
24"
3 1/2"
4 1/2"
4 1/8"
8 3/4"
12 1/8"



Figs. 216, 217, and 218.

A well-constructed pump on these lines is shown in figs. 216–218, made by Messrs Frank Pearn & Co., Manchester, who supplied the drawing. It is suitable for belt driving by gas or oil engine. The figure is self-explanatory. The pump barrels are of close-grained cast iron, and, together with the valve chambers and vacuum vessel, are formed in one, having a trough which collects leakage from the glands. The valves and seats are of gun-metal and of the mitre type. The rams are of the trunk type, and work through cast-iron glands and neck rings. The crank shaft and connecting rods are of forged steel, and run in brass bushes of the usual type. This class of pump may be horizontal or vertical, as is found most suitable. In the illustration the pump is seen belt-driven. This is quite a satisfactory arrangement, the gearing for reducing speed being an integral part of the pump. Modern practice, however, tends to putting the pump and engine (or electric motor) on the same base plate, placed side by side, and the belt to be dispensed with. The engine shaft drives on to the pump counter-shaft by means of a friction clutch, which is actuated by a hand wheel; this arrangement is necessary in order that the engine can be started up without the load on, and without inducing a jar on the pump. An arrangement of this kind forms a very compact machine, as it takes up very little space and is very well adapted for small installations. Regarding the details of the three-throw pump, the principle is the same in all, but details differ with the several makers. From a mechanical point of view, the Worthington design is sound and has been selected for description. Fig. 219 represents a section of the single-acting three-throw type. All three-throw pumps will be appreciated by the engineer when he considers that the speed of the plunger in any pump is not uniform throughout the stroke, because the crank has to travel in a circle, while the motion of the plunger is a straight line. The velocity of the crank being constant, the velocity of the plunger increases rapidly from zero to the maximum, and decreases from this point to the end of the stroke. Again, the velocity of discharge is proportional to the velocity of the plunger at any instant. Bearing in mind that water is considered to be incompressible, the pump and delivery pipe will always be subject to shocks dependent on the speed of the pump. Hence it will be observed that the triplex pump should provide a very uniform discharge. The mechanical details of the pump will be readily understood and appreciated by the student of machine design. The water chest is a particular feature of the Worthington pump, and is so constructed that it can be separated from the cylinders in case of repairs, a valuable feature when pumping dirty water. The hand hole plate is bolted on, and when removed the valves are easily got at. Most makers provide special valves best suited for the liquid to be pumped. Regarding sewage pumps, Mr Powis Bale states that:[1]

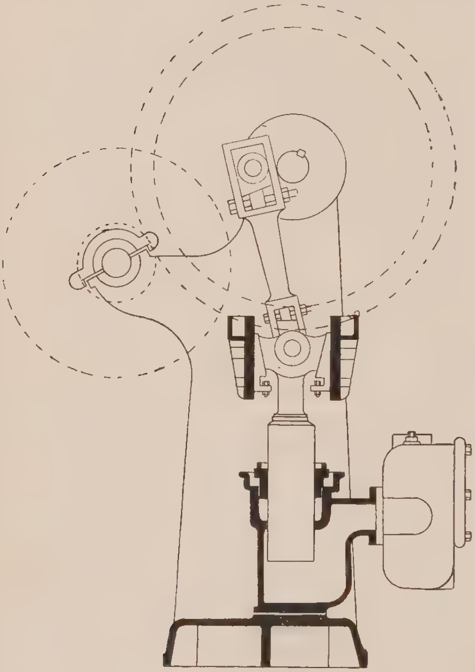


Fig. 219.

"A long-stroke plunger pump is generally to be preferred to a piston pump for this duty. It is important that the liquid has as few reversals of its flow as possible, and that there be no complications in the passages or corners where the sewage can accumulate. The valves should be as large and free as possible, and readily examined; sometimes, for this work, the valve seats are made movable as well as the valves. Wrought-iron clack valves with leather seats are used for sewage purposes, and also double-beat valves."

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[1] *Pumps and Pumping*, Crosby Lockwood Co.

For very heavy liquids, such as sewage sludge and trades' wastes from chemical works, paper mills, etc., balanced ball valves give very good results.

When the engineer who has a sewerage scheme to carry out has decided upon what class of pump is most suited to the special requirements of the case, the two most important duties that fall on him are the ordering of the pump from the makers, and the supervision of the erection of the same when it arrives on the scene of operations. This being a book dealing with sewerage work, this chapter is not in any way intended to be a treatise on pumps. What is aimed at is to point out to the reader what class of machine is most suited to the individual requirements, and briefly to describe that machine, the design being quite a separate matter. Regarding the inquiries from manufacturers, it is essential that, in order that they may do duty to themselves, full and accurate details should be furnished, to say nothing of the saving of valuable time and needless correspondence. It should be stated:

1. For what purpose the pump is to be used.
2. What is the maximum quantity of water or other liquid to be pumped in gallons per hour.
3. To what vertical height is the liquid to be raised.
4. The height of suction, length of delivery pipe, and number of sharp bends; if they exist, give size and state condition of interiors.
5. The proposed motive power, and pressure of steam or air supply, if any.
6. Condition of liquid to be pumped, viz. gritty, muddy, acidulous, etc.

Again, like centrifugal pumps, there are certain appurtenances which are erected on the spot under the supervision of the engineer, but are not integral parts of the pump itself. For instance, there is the suction pipe, which must not be smaller than that recommended by the pump-maker; if very long (which is a condition to be avoided), it must be larger in order to allow for the extra friction, which might spoil the vacuum. It should be laid at a uniform gradient, in order to avoid summits and air-pockets. Bends should also be avoided if possible, while the slope of the pipe should not be less than 1–100. It is important that the joints are quite tight. In the rising main, leaks, of course, will be readily perceptible; but not so in the suction, where they will continue often for years, much to the detriment of the efficient working of the pump. It should always be tested by a hand force-pump before filling in, to a pressure of about 30 lb. per sq. in. Cast-iron flanged pipes are by far the most suitable for suction and delivery mains from pumps, but spigot-and-socket pipes with joints of run lead give good results when the pressure is not very great. All valves on suction and discharge pipes should be full-way gate valves. A foot valve of suitable type must be provided, and also a strainer. The strainer should be examined to see that the total area of its openings is at least twice the area of the suction pipe. In working, it is advisable to clean the strainers of pumps very often, a precaution too often overlooked. When complete, the suction pipe should always be well swilled out with water immediately before connection to the pump.

Raising Sewage by Compressed Air.—Where the whole sewage of a district flows by gravity to one central point preparatory to its being raised, it is usual to erect at that point a pumping-station containing one or more units of the class already described. There are often cases, however, where it will be prudent and economical, if not imperative, to raise sewage at several points in a district. To place independent plants at each of these points will at once appear to the reader quite impracticable, unless the flows to be dealt with are exceptionally large. Even automatically controlled, electrically driven units will want constant attention for oiling, cleaning, etc., which is a point in disfavour of that system. Again, modern engineering tends to the raising of sewage in small quantities at many points; and so important is the question and so efficient the system, that the subject of compressed air will be dealt with at some length. Moreover, information of a practical nature on the subject is not too abundant; this, together with the writer's experience of the methods and his confidence of its value, will, it is hoped, serve as an explanation of this departure from the actual subject of sewerage.

First of all, there is the automatic system of Messrs Adams & Co., in which no air-compressing machinery is required, but in which sewage from a high level is made to raise another portion from a low level to a gravitational sewer some distance midway between the two. The system has admittedly rather narrow limits, hilly districts only being suitable, except with certain modifications, but where practicable the plant has much to recommend it.

Details of the apparatus are shown in figs. 220, 221, 222. Starting at the high-level end, sewage flows into a tank by means of a pipe on which there is a syphon trap. In this tank is a flushing syphon which, when the liquid has risen to a predetermined level, draws it off rapidly into a steel cylinder previously filled with air at atmospheric pressure. The flow of liquid displaces the air into the air-pipe and along to the forcing cylinder. In the meantime it has risen and flowed out down the long leg of another syphon which draws off all the contents; these flow by gravity to the intercepting sewer, and the process can then be repeated. Meanwhile, however, the air so displaced has been doing useful work, since, having travelled along a steel pipe to the forcing chamber, it has entered a similar cylinder to that from which it was displaced. This latter was nearly or quite full of sewage which had flowed into it from a low level. The air exerting its pressure has now closed the valve in the chamber on the incoming sewage for the time being, and forced out the stored-up liquid through a steel or cast-iron rising main into the intercepting sewer, and so raised it. The process is continually repeated. The makers design their plants according to individual requirements, but in all cases it is essential that:

1. The air pipe must be higher than the syphon pipe. This is to prevent sewage in the air cylinder from finding its way into the air pipe.
2. The rising main must start at the bottom of the forcing cylinder.
3. The air pipe must enter at the top, and preferably at the opposite side.
4. The size of the flush tank must allow of the complete filling of the air cylinder and two syphon pipes + a few extra gallons.
5. Finally, the flow from the high level must always be in excess of that from the low, under all circumstances and conditions.

A plan and section of such a scheme are shown in figs. 223 and 224.

It is also quite possible to use fresh water instead of sewage for working the system, but it then constitutes an element of expense (unless the supply is from some brook or stream), which defeats the object of the invention, namely, to raise sewage by means of sewage without cost.

A modification of the above system is that in which small quantities of sewage from the basements of hotels and large public buildings are raised by that from the higher landings, when the level of the basement would happen to be below the level of the public sewers, as is often the case. The distance apart of the air and forcing cylinders is immaterial, but the greater the distance the greater will be the volume required at the higher level. The flush tank need not be placed underground, as shown; it may be placed on a tower, as is done at Hoylake in Cheshire.

Where the above automatic system is impracticable or inefficient, a supply of compressed air must be provided to operate ejectors. The best known of these is Shone's, which is illustrated in diagrammatic section in fig. 225. It is made by Messrs Hughes & Lancaster, Ruabon. It works by compressed air acting directly upon the liquid, and is specially adapted for working in units, the power being generated in a central station and conveyed in steel mains. At × × are two flap valves of very simple construction. Sewage flows in by gravity, lifts the float, and gradually immerses the bell. The air in this becomes entrapped and admits compressed air from the main; the pressure closes the inlet valve, and, the outlet valve opening, the whole contents are immediately displaced. The falling of the float closes the air-supply valve and the process is repeated. The ejectors are usually placed in brick chambers of the usual pattern, and in bad ground in cast-iron tubbing. A scheme is shown in figs. 226, 227, and 228.

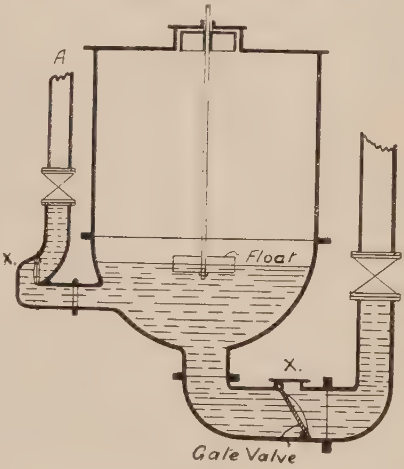

FIG. 225.

Of recent years the scope of the ejector system has been considerably extended. The equipment shown in figs. 226–228 is intended for operation by air supplied from a central compressing station which may operate half a dozen or more ejectors. That, in fact, was the original idea when ejectors were introduced. Many circumstances, however, are not wholly favourable to this arrangement, and one is the loss in the air mains, not necessarily wholly by leakage but by transmission losses in the shape of friction. Against this admittedly has to be put the higher efficiency of a central compressing station as against smaller ones; but this arrangement of having a small self-contained, electrically driven, and automatically operated compressor alongside the ejector is one which may often prove very favourable. The working of the ejector automatically starts and stops the motor, and, in the event of electricity being unavailable, this may even be effected by a small water motor operated from the town's mains to start up a petrol-driven compressor.

Air Compressors.—These fall into two main classes:

1. Slow-speed machines.
2. High-speed machines.

Until quite recently the former type of machine was universally employed, and for large plant, such as collieries, this type still holds the field. The first aim of compressor designers is to keep the percentage of clearance between the piston and cylinder covers at the dead centres as small as possible, because all the air entrapped in this space has to expand to initial atmospheric pressure (at least) before any admission can take place, which will, of course, affect the volumetric efficiency, because admission cannot commence before the piston has travelled some distance (about 10 per cent.) of its stroke. Many makers of compressors make no allowance for this, a fact which wants very careful investigation by the engineer. For small installations, single-stage machines are used, but the expense of a two-stage compressor is usually warranted. The limit of the single-stage machine would be about 200 cub. ft. of air per minute at a receiver pressure at 100 lb. per sq. in. When any single unit is required to give greater duties than this, it is generally considered prudent and economical to install a two-stage machine having an intercooler. Another point which it is very important to bring before those whose experience with compressed air is only small is, that the piston rings require very careful fitting, more so than the steam cylinders. It is a common thing to see a new machine giving almost inconceivably good indicator cards from the air cylinder—that is, very small diagrams, with which the inexperienced engineer would be agreeably satisfied, when perhaps all the time a leakage is taking place past the piston rings with this result. The reason for the desirability of small diagrams is because they show that the compression is approaching isothermal (viz. having an equal degree of heat), and this is what all designers are aiming at. The amount of work required to compress 1 lb. of air to any pressure will be smallest when the compression approaches isothermal. If none of the heat is absorbed, however, the curve rapidly approaches the adiabatic.

It will be prudent and economical to lay down a two-stage compressor; in fact, many of the smaller high-speed compressors are also made two-stage, so apparent are the advantages of doing so. The reason is as follows:—

When air or other gas is compressed a rise of temperature takes place, which in itself is a loss of power, but the true extent of such loss is not always exactly ascertainable. An air-compressor cylinder is water cooled in order to abstract the heat. If it was all absorbed by the water, instantaneously compression would take place at uniform temperature (that of the water), known as *isothermal*; this, of course, is quite impossible. On the other hand, if none of the heat generated was lost, the compression would take place under *adiabatic* laws, which is also impossible. Now a given weight of air at a given pressure occupies a volume which is proportional to its *absolute* temperature; consequently the volumes at all pressures in isothermal compression are less than those in adiabatic; hence the heat remaining in the air represents so much loss of energy. Apart from mechanical considerations, economical ones at once demand something approaching the isothermal conditions during actual compression. The jacket water, however, has been found to be of little use other than keeping the cylinder wall cool within reasonable limits for efficient lubrication; and, so far as the cylinder is concerned, the compression is very nearly adiabatic, hence economy must be looked for elsewhere. This consideration has led to the two-stage machine. It must not be supposed by the reader that the mere advantage and purpose of a two-stage machine is to get a higher pressure. The idea is to withdraw the air in the middle of the process, so to speak, cool it, and complete it afterwards; and that is what is actually done, the air passing from the first cylinder through a series of water-cooled tubes (very much like a surface condenser), called an *intercooler*, the saving being greater with higher pressures. In any case, the lower *average* temperature results in a lower average pressure, with the result that less power is required to compress a given volume of air. Again, a very important point is the clearance space between piston and cylinder covers. As stated, mechanically this can be reduced to narrow limits; but it must always be borne in mind what was said about the entrapped air; and as the final pressure in the low-pressure cylinder of a two-stage machine is much less than that in a single-stage one, this loss is much reduced. The air from a two-stage machine is always drier than from a single-stage one, as moisture is deposited in the intercooler pipes, where it has less chance of doing damage than in the mains, the former being made of brass, the latter of steel.

In fig. 229 is illustrated a modern type of slow-speed high-class two-stage compressor. The drawing does not require much description, as the design is all very straightforward, and is on the lines of the Worthington Company's machines. An important item is the positively moved valves of the air cylinders. Small engines invariably have valves of the spring-loaded poppet type, which are suited for the purpose; but on large high-class machines, mechanically moved valves give better results. In any case, high-class firms always make the poppet valves of the very best construction, from solid bar steel instead of cast iron, while the seats should be of hard bronze. In the compressor illustrated the valves are what are known as the Corliss type, semi-rotary and positively controlled. They are placed in the cylinder covers, which allows the air to enter by the shortest and quickest passage by a single large opening, and reduces to a minimum the heating surface with which the incoming air comes in contact. On the whole, the type of engine described has much to recommend it; the slow, even, silent working tends to freedom from repair and breakdown; moreover, the slow-speed engine is always more efficient and can be adjusted to a greater nicety than a high-speed. On the other hand, the use of these large expensive compressors is confined to those places where a large supply of air is required, where capital outlay has not much moment. This is not so much on the actual machinery itself as upon the large engine-house and foundations, etc., and land required. In many, perhaps the great majority of, sewage schemes employing the ejector principle, circumstances will not warrant the laying down of a large plant, and the high-speed compressor will be the most likely to serve the purpose. Various firms have paid much attention to this type of late years, and it has now reached a state of efficiency little dreamed of by the old advocates of slow speed, and nothing but slow speed,

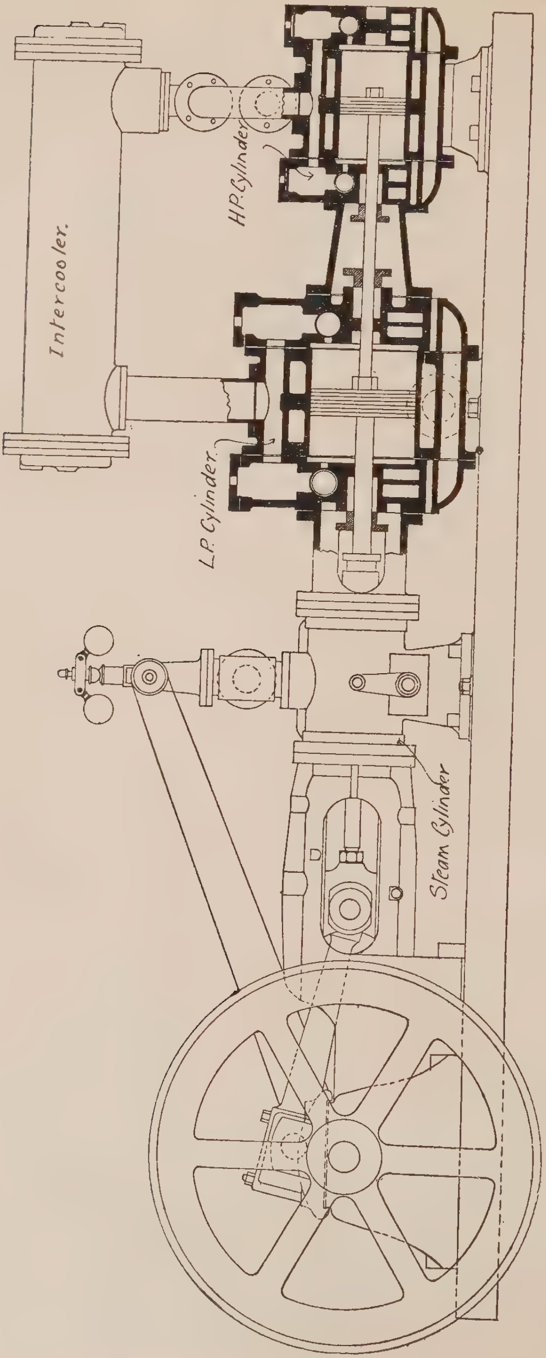

Fig. 229.

bearing in mind also the great advance in improvement of the high-speed steam-engine. For instance, Messrs Alley & Maclellan, the well-known pioneers of the latter type, state that for a compressor of 5000 cub. ft. of free air capacity per minute, the slow-speed type requires 418 cub. yds. of material in the foundations, while, all other circumstances being equal, the high-speed self-contained steam-driven engine requires 55, the floor space of the latter being 23 ft. 3 in. × 8 ft. and the former 47 ft. × 20 ft., with a saving of at least 10 per cent. on first cost of engine. These machines have forced lubrication and automatic valves for the air. A sectional drawing of an engine of the high-speed type (vertical) is shown in fig. 230 for driving by belt or gearing from some source of power. Where steam is employed, the steam cylinders are placed above the air cylinders and a good combination results. Two-stage compression and intercooling is usually provided for. In addition to the advantage already set forth, in the high-speed type there is a further one of reduced stresses, and consequent quieter running and increased life.

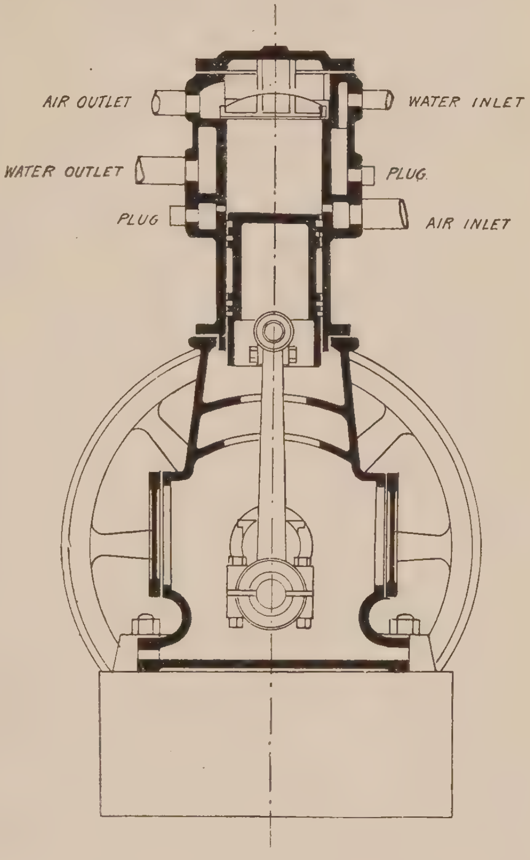

Fig. 230.

In fig. 231 a special type of compressor attached to a gas engine, all on one bed-plate, is shown. It is self-contained, and is a suitable small unit. It is made by the same firm as make Shone's ejectors. For use in connection therewith, an electrically driven engine of the same type is illustrated in fig. 232.

Flow of Compressed Air.—The flow of the air in pipes is important. The density varies with the pressure, due to air being a very elastic substance as opposed to water. Hence the frictional losses are somewhat complicated. For instance, the air enters the pipe at a certain pressure and velocity, some of the pressure is bound to be lost in overcoming friction, with a consequent increase of volume (Boyle's law), and at the same time velocity of flow. The result is that at no two points in the pipe line is the loss of pressure the same in a unit distance. Compare this with the flow of water

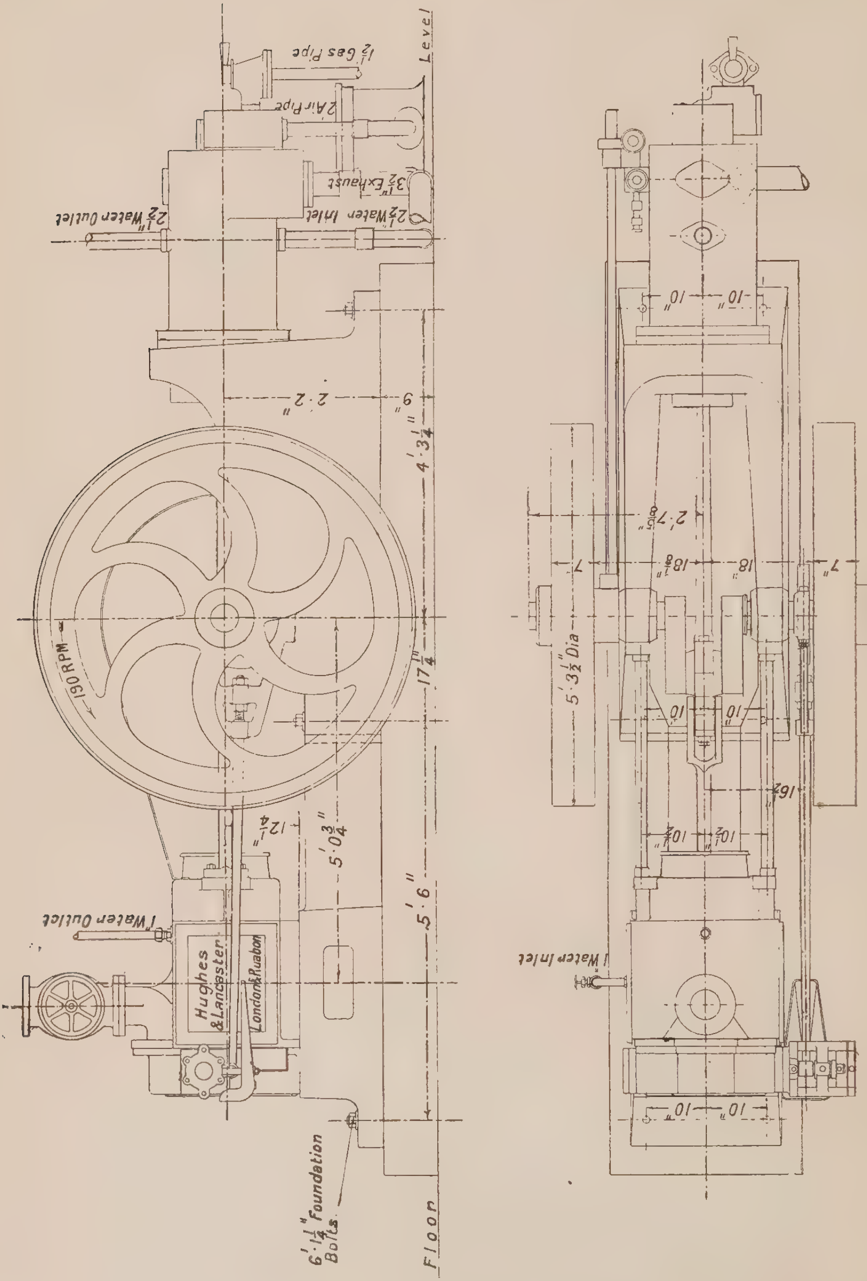
Level
1½" Gas Pipe
2" Air Pipe
3½" Exhaust
2½" Water Inlet
2½" Water Outlet
2' 2"
6"
4' 3¼"
17¼"
190 RPM
12¼"
5' 0¾"
5' 6"
1" Water Outlet
Hughes & Lancaster
London & Ruabon
6' 1¼" Foundation Bolts
Floor
10"
10"
2' 7⅝"
7"
18⅛"
18"
7"
5' 3½" Dia
10"
10"
16½"
10½"
10½"
1" Water Inlet
10"
10"

FIG. 231.

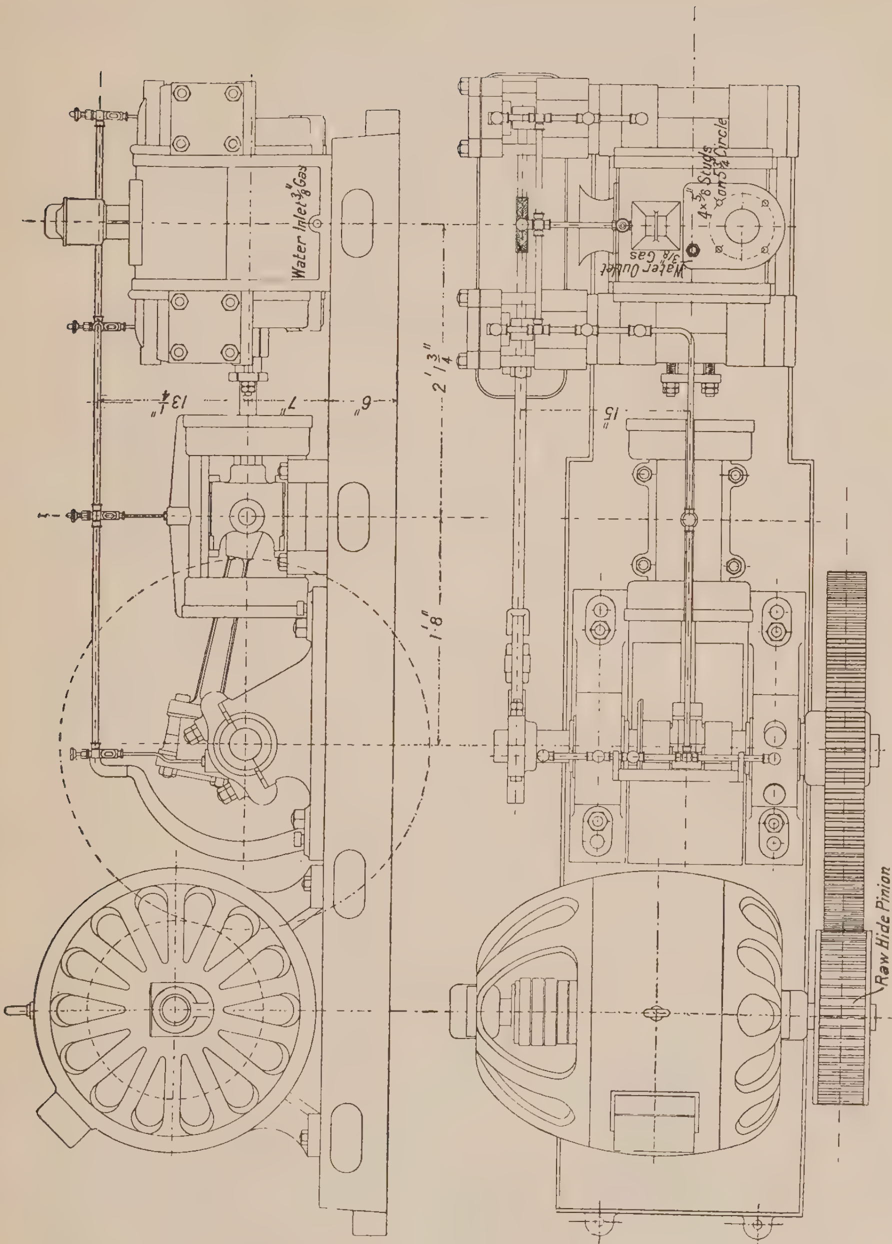

FIG. 232.—Motor-driven Air Compressor, Cylinder 9-in. diameter × 8-in. stroke.

in a closed pipe. Its incompressibility does not allow of any increase in the velocity of flow, although the pressure does decrease. A fundamental equation for the loss of pressure in a pipe line is constructed as follows :—

Let P=absolute initial air pressure } lb. per sq. in.
p= ,, terminal air pressure } lb. per sq. in.
L=length of pipe in feet.
d=diameter of pipe in inches.
Q=volume of free air in cubic feet per minute, passing through the pipe.

Then

$$P^2-p^2=\frac{0\cdot0006Q^2L}{d^5}.$$

Again, the maximum percentage of useful effect between the air compressor and the motor cannot be taken at more than 30 per cent. Assuming a direct-driven air compressor of 85 per cent. efficiency; 75 per cent. efficiency in compressing, 10 per cent. loss per mile on the mains (this is the minimum loss, too, when the mains are of the best construction), and 50 per cent. efficiency of the compressed-air motor. Thus, if the steam or other motive power develops 100 I.H.P. at one mile from the compressor, we shall have

$$100\times0\cdot85\times0\cdot75\times0\cdot9\times0\cdot5=28\cdot69 \text{ H.P.},$$

or if the distance is half a mile,

$$100\times0\cdot85\times0\cdot75\times0\cdot95\times0\cdot5=30\cdot28 \text{ H.P.}$$

The velocity of air in the mains must not exceed 40 ft. per second.

The coefficient of friction for the flow of air through wrought- and cast-iron pipes varies inversely as the diameter of the pipes, and is obtained by Professor W. C. Unwin's formula as follows :—

$$\text{Coefficient}=0\cdot0027\left(1+\frac{3}{10d}\right),$$

where d is the diameter of the pipes in feet.

This coefficient is 0·00377 for 7½-in. diameter pipes.
,, ,, ,, 0·00449 ,, 6-in. ,, ,,

To obtain good results from a compressed-air motor, it is advisable, in all cases where possible, to reheat the compressed air up to 300° or 400° F., at a point near to the motor, the economy being increased, and difficulties with ice, etc., in the motor being removed.

Equipment of an Air System.—When leaving the last-stage air cylinders the compressed air should be conducted into a *receiver*. They are usually very similar to a vertical steam-boiler shell, and should be made of high-grade boiler steel, with double-riveted longitudinal and single-riveted circumferential seams. The inlet pipe should be as far as possible from the outlet, so as to provide the longest travel for the air to cool and precipitate moisture, to intercept which a drain cock is provided. A safety valve, pressure gauge, and manhole usually complete the apparatus. There is no particular reason why the receivers should be vertical, but they usually are so. An error often committed is that of the tank being too small, and in order to equalise the flow it is essential that the receiver be of a capacity at least equal to three minutes' discharge of the compressor. With ejectors an even larger reservoir is to be advised, owing to their intermittent working, which might cause the machine to run "light" a needless amount should the capacity be small. Again, the surface of the reservoir is very useful in causing deposition of moisture. The reservoirs should be tested to double the working pressure. As discussed with pumps, one of the objects of this chapter is not so much to treat on the design of air systems, as to place the reader in a position to deal with the manufacturing firms who supply the machinery.

For instance, the inquiries made to these people should be accompanied by explicit information for their guidance, consisting of :

1. Motive power to be used.
2. Discharge pressure of air.
3. Cubic feet of free air to be compressed per minute.
4. State the inlet pressure if not atmospheric.
5. Level above sea.
6. If valves are to be positive or automatic.
7. Available floor space.

The most important point that the buyer must be clear on with the makers is the capacity of any given machine. These statements, especially by second-rate firms, are very misleading, and usually made to their advantage. The policy of rating air-compressors by the volume swept out cannot be too strongly deprecated, because it may only be about 60 per cent. of the *air actually handled.* This latter term must be that upon which the guarantee is dependent. The actual volumetric efficiency will always be more or less greater in the slow-speed machine than the high-speed, but modern high-speed machines usually make up for the loss in other points.

Regarding the system of piping which conveys the compressed air to the ejector or other machine dependent upon it. The air-inlet pipe to the cylinder should be in such a position as to ensure a delivery of clean, dry, cool air. Its section is usually square and material wood, as this is a very good heat insulator. The pipe should be free from angles and bends, and must have some sort of a strainer fitted to it to intercept foreign bodies. It should be of ample area to reduce friction. It usually consists of a square box filled with cotton-wool placed between two gauze screens. From the last compressing cylinder the air usually passes direct to the reservoir, but in some cases it may be deemed prudent to cool the air further by what is known as an "after-cooler." This piece of apparatus is generally installed in cases where the capacity of the compressors is over 500 cub. ft. of free air per minute. One of the principal advantages is the deposition of moisture. Atmospheric air always contains moisture. Owing to the heat generated in compression, this is usually not deposited as easily as might be supposed. This is very important, because its condensation in the pipes not only tends to corrode them, but to fill them up and eventually to stop the air supply. The oil carried over from the air cylinders can also be intercepted and removed.

The after-cooler is very much of the same style as the intercooler, the shell and the tubes being of steel, placed vertically, and around which water circulates freely. A check valve should always be placed between compressor and reservoir to enable the former to be disconnected without "blowing down." They must never be of the screw-down type, as they may be left shut against load by accident, while, if the compressors are gas-driven without a clutch, a relief valve must also be placed in the same position as the check valve.

The distributing main is usually composed of solid drawn-steel tubing, although the lap-welded type is quite suitable. The flange joints should be loose and the packing rings thick. The size of the pipe should limit the velocity to 20 ft. per second, and the following table, from Messrs Alley & Maclellan's catalogue, will be useful :—

TABLE XXII.—AIR AT 100 LB. PRESSURE PASSED BY STEEL PIPES.

Internal diameter inches	1	1½	2	2½	3	4	5	6	7	8	10
Cubic feet per minute .	51	115	204	319	460	816	1276	1840	2505	3264	5104
Loss of pressure per 1000 ft. in lb. per sq. in. .	8	5·35	4·13	3·55	3·07	2·31	1·88	1·67	1·49	1·37	1·03

It is wise to bear in mind the possibility of future extension, and to put in a size of pipe that will avoid the necessity of renewal or duplication at an early subsequent date ; the branches can easily be determined when it is borne in mind that the capacity varies as the square of the diameter.

In sewerage work the pipes will have to be underground in most cases, and they must be well protected from heavy traffic. It is one of those conditions which are unfortunate, because the line cannot be readily inspected for leaks, and these may go on quite indefinitely, unlike those in water mains, which usually soon show up. In testing, the joints are painted with soapy water to reveal leaks. The pipes should be laid with even falls as far as possible to small sumps, from which the moisture can be periodically withdrawn. It is also most essential to see that the pipes are clear of all rubbish before connecting them up.

When the plant is duly erected it should be tested in the presence of the engineer. If he is fully qualified to test engines no word of advice is necessary, but civil engineers do not always get the opportunity of becoming proficient in this, and it is necessary that the essential points should be understood by the reader.

The several items to be accurately determined are as follows :—

1. Height of barometer.
2. Atmospheric temperature in the building where test is conducted.
3. Receiver pressure.
4. ,, temperature.
5. Speed in R.P.M.
6. Time taken to fill receiver from atmosphere.
7. Revolutions taken to fill receiver from counter.
8. Volume swept out by piston.
9. Indicated horse-power of L.P. air cylinder.[1]
10. ,, ,, ,, H.P. ,, ,,
11. Mean I.H.P. of both cylinders.
12. The total air compressed in cubic feet.
13. The capacity of the air cylinder.

$\frac{12}{13} \times 100 =$ efficiency (volumetric).

---

[1] It would be quite out of place here to treat of the use of the indicator. Those who lack the knowledge should consult standard works on the subject.

If the receiver is of fair size, correction for temperature need not be made.

Motive Power.—In large stations of big cities, where considerable volumes are pumped and the machines kept going night and day, steam plant is generally laid down. The pumps being centrifugal, the engines are invariably of the high-speed type on the same shaft as the pump. They may be simple, compound, or triple expansion, the second named being the most usual, while, if space is cramped, the tandem compound is a good machine. The engines are usually enclosed and forced lubrication employed. The boilers may be either of the Lancashire or Cornish type, having one or two internal furnaces as the case may be, or the water-tube pattern of the Babcock or Hornsby type. The load being generally more or less constant during different periods of the day, the Lancashire type is generally preferred for this particular purpose, especially where there is ample storage room to equalise the flow to the pumps during heavy rains. Such tanks should always be provided, and in small places they may allow of the engines being shut down at night. For small towns a steam plant would not prove economical, and gas engines or oil engines are usually employed for the purpose. In very small installations a horizontal engine driving the pump by rope or belt is most convenient. As the plant becomes larger, a vertical 3- or 4-cylinder engine, on the same shaft as the pump, provides an efficient machine. When the power of gas engines exceeds 20 horsepower, it may pay to put down a suction producer; and if over 100 horsepower, a pressure producer.

Small oil engines are usually of a very similar type to gas engines, and work on ordinary commercial paraffin. Large paraffin engines are not so economical as producer gas engines, and are seldom now installed.

During the last fifteen years power generators have undergone considerable change. Steam-pumping and compressing plants are becoming rare, because both gas and oil engines are much cheaper to operate. The extended distribution of electricity makes the source of power one of primary importance, and especially is it well suited to the operation of centrifugal pumps.

The gas engine has become rather overshadowed of late by the remarkable improvements in oil engines using cheap low-grade fuel. Classified broadly as heavy oil engines, they fall into three main classes:

1. The Diesel with its air-blast injector, which is a relatively costly machine but highly efficient, and is suited to powers of 500 H.P. and over.
2. The cold-starting engine, which has airless injection, is generally well suited to continuously operated plants, while its somewhat high initial cost may be justified by its economy in fuel.
3. The semi-Diesel engine, which is relatively cheap in first cost, is very suitable for all classes of small pumping plant and those intermittently operated.

Despite these relative new-comers into the power field, the gas engine has the outstanding feature of extreme reliability, it is often cheaper than an oil engine, and really compares favourably in operating cost.

Pump Calculations.—When the engineer has ascertained how much sewage has to be raised and what means he is going to adopt to raise it, it is necessary to ascertain what horse-power will be required, because upon this will depend the annual cost of this part of the scheme, which, if it prove likely to be unusual, may induce the designer to seek other means of getting rid of the sewage by means of long detours, which would perhaps be cheaper in the end. The decision of such an important question, where public money is spent, falls on the engineer. It is his duty to consider each case on its merits, for which purpose common sense and practical experience are needed.

The following examples are instructive :—

(1) What size of engine is required to drive a three-throw ram pump, having 9-in. rams and a 12-in. stroke, running at 35 revs. per minute, capacity$=$15,000 gals. per hour ? Total head 950 ft., gearing 4 to 1. Available steam pressure 45 lb. per sq. in.

Three-throw single-acting ram pumps, 9-in. diameter by 12-in. stroke, 35 revs. per minute, delivering 15,000 gals. per hour ; gearing 4 to 1 ; steam pressure, 45 lb. It is evident that the engine must run $35\times4=140$ revs. per minute. 420 ft. per minute is a suitable piston speed. Then $\frac{420}{140}=3$ ft. double stroke, or 18-in. stroke of piston. 15,000 gals. per hour$=\frac{15000}{60}=250$ gals. per minute against a head of 950 ft. 1 gal.$=$10 lb. $\frac{250\times10\times950}{33000}=72$ water horse-power. As the efficiency of a geared pumping engine is only about 66 per cent., 33 per cent. must be added, or 24 horse-power, to the theoretical power, making a total of 96, which is the indicated horse-power that the engine must give out. Steam pressure, 45 lb.—say 40 lb. on piston, or 55 lb. absolute. Cut-off, say $\frac{3}{4}$ stroke. Constant for expanding steam at a cut-off of $\frac{3}{4}$ stroke$=0{\cdot}968$. $55\times0{\cdot}968=53{\cdot}24$ lb. Back pressure$=15+3=18$ lb. $53{\cdot}24-18=35{\cdot}24$ lb. Diagram factor of 0·9 to allow for losses. $35{\cdot}24\times0{\cdot}9=31{\cdot}716$ lb., say 32 lb. M.E.P. Now $\frac{96\times33000}{420\times32}=236$ sq. in., which is the area of cylinder required. This may be either one or two cylinders, and works out at about 18 × 18 in. single-cylinder, or about 13 × 18 in. double-cylinder engine, running at 140 revs. per minute in either case.

Or, take the case of four $6\frac{1}{2}$-in. rams with a 2-ft. stroke at 25 revs. per minute.

(2) Same duty as before, but engine-driven, 2-ft. stroke, and running at 25 revs. per minute. Steam pressure, 45 lb. per sq. in. In direct engine-driven pumps the mechanical efficiency should be about 90 per cent. Water horse-power as before$=72$. Add 10 per cent.$=7{\cdot}2$, say 8. Then engine must furnish 80 I.H.P. when running at 25 revs. per minute, or a piston speed of $25\times2\times2=100$ ft. per minute. M.E.P.$=$32 lb. Proceeding on similar lines to (1), there is $\frac{80\times33000}{32\times100}=825$ sq. in. cylinder area, which gives either one 33 × 24 in. stroke single-cylinder engine, or one 23 × 24 in. stroke double-cylinder engine, running at 25 revs. per minute, and cutting off at $\frac{3}{4}$ stroke in either case. These cylinders come out rather large in diameter, but this is due to the low steam-pressure in both cases, and is further aggravated by the low piston-speed in (2). In all cases the area lost by piston rods has been allowed for, and the diameters given in " round figures."

Take now the case of driving a centrifugal pump by gas engine under the following conditions:—

All pipes $3\frac{1}{2}$-in. steam pipe, 13-ft. suction, one elbow, then 90 ft. of pipe rising 1 in 25, then two more elbows before the pump is reached; speed of pump 1260 R.P.M.; duty 4000 gals. per hour; two elbows on delivery.

$$\text{I.H.P.} = \frac{\text{P} \times \text{H}_{mano}}{3600 \times 550 \times \eta_t},$$

where I.H.P.=indicated horse-power required (measured in gas-engine cylinder); P=lb. of water delivered per hour; H_{mano}=manometric head (*i.e.* suction head+pressure head+friction head+loss of head through delivery at a certain velocity); $3600=60\times60$=number of seconds per hour; 550=number of ft.-lb. per second=1 H.P.; η_t=total mechanical efficiency of apparatus under consideration. P in the present case is 4000 gals. per hour, or 40,000 lb. per hour.

$$\begin{aligned} \text{H}_{mano} = \text{suction head} \; . \; . \; . \; . \; . \; &= 16{\cdot}6 \\ \text{pressure head} \; . \; . \; . \; . \; . \; &= 18{\cdot}0 \text{ (given)} \\ \text{friction head } (h_t) \; . \; . \; . \; . \; &= \;\; 2{\cdot}94 \\ \text{loss at outflow} \; . \; . \; . \; . \; &= \;\; 0{\cdot}11 \\ &\overline{\;37{\cdot}65 \text{ ft.}} \end{aligned}$$

obtained as follows: Suction head, 13 ft.+90 ft., rising 1 in 25=$13+\frac{90}{25}$ $=13+3{\cdot}6=16{\cdot}6$ ft. Friction head,

$$\text{Log } h = \log \text{L} + 2 \log \text{P} - 5{\cdot}16 \log \text{D} - 8{\cdot}0913987,$$

h being the friction head in the straight pipes, L=length of main in feet, D=pipe diameter in inches. L is made up as follows: 13+90+18= 121 ft.

$$\begin{aligned} \text{Log } h &= \log 121 + 2 \log 40{,}000 - 5{\cdot}16 \log 3{\cdot}5 - 8{\cdot}0913987 \\ &= 2{\cdot}08279 + (2 \times 4{\cdot}60206) - (5{\cdot}16 \times 0{\cdot}54407) - 8{\cdot}0913987 \\ &= 2{\cdot}08279 + 9{\cdot}20412 - 2{\cdot}8074012 - 8{\cdot}0913987 \\ &= 0{\cdot}3881. \quad \therefore h = 2{\cdot}445 \text{ ft.} \end{aligned}$$

To this must be added the friction due to the elbows, which is calculated as follows:—

$$h_e = \frac{\text{CV}^2}{2g}.$$

C is taken at 0·5 in the present case, as the elbows are probably steam-pipe fittings. The velocity V is determined thus:

$$\frac{p}{3600 \times \text{A}}.$$

A is the area of the pipe (here 3·5 in. in diameter) in sq. ft. 3 in. is 0·25 ft., and 0·5 in. is one-sixth of 3 in.; therefore $\frac{0{\cdot}25}{6}=0{\cdot}0416$ and 3·5 in. $=0{\cdot}2916$ ft., giving an area of about 0·0668 sq. ft. p is the water quantity per hour, expressed in cubic feet, or 4000 gals. × 0·1605 = 642 cub. ft. per hour. Then

$$V=\frac{642}{3600\times 0{\cdot}0668}=\frac{642}{240{\cdot}48}=2{\cdot}66 \text{ ft. per second,}$$

and

$$h_e=\frac{0{\cdot}5\times 2{\cdot}66^2}{2\times 32}=\frac{0{\cdot}5\times 7{\cdot}0756}{64}=0{\cdot}055278 \text{ ft.}$$

There being five knees, the above amount is multiplied by 5, and allowing the equivalent of two knees for the suction strainer, and a similar amount for the regulating or stop valve,

$$0{\cdot}0553\times 9=0{\cdot}4977 \text{ ft.}=h_e.$$

Adding the previous result $=2{\cdot}445$ ft. $=h$,

$$h_t(\text{total})=2{\cdot}9427 \text{ ft. is obtained.}$$

The loss due to outflow is determined as follows :—

$$hl=\frac{v^2}{2g};$$

or in the present case,

$$hl=\frac{2{\cdot}66^2}{64}=\frac{7{\cdot}0756}{64}=0{\cdot}110556 \text{ ft.}$$

The total efficiency η_t is the result of the combined efficiencies of the pump, belt drives, countershaft, and gas engine, which may be estimated as follows : Efficiency of pump, 0·6 ; efficiency of each belt drive, 0·97 ; efficiency of countershaft, 0·95 ; and efficiency of small gas engine = 0·6. $\therefore\ \eta_t=0{\cdot}6\times 0{\cdot}97\times 0{\cdot}97\times 0{\cdot}95\times 0{\cdot}6=0{\cdot}3218$.

The main formula can now be resolved as follows :—

$$\text{I.H.P.}=\frac{\text{P}\times \text{H}_{mano}}{3600\times 550\times \eta_t}=\frac{40000\times 37{\cdot}65}{3600\times 550\times 0{\cdot}3218}=2{\cdot}36.$$

Power to Compress Air.—Consider compressing 1000 cub. ft. of free air per minute with 100 lb. pressure, using a two-stage engine. First find approximately the mean effective pressure of the air cylinders

$$=\text{M.E.P.}=\frac{n}{n-1}\times x\times \text{P}_a\left\{\left(\frac{\text{P}_c}{\text{P}_a}\right)^{\frac{n-1}{xn}}-1\right\}$$

n = coefficient = 1·25.
x = number of stages, in this case = 2.

$$\left.\begin{array}{l}\text{P}_a=\text{absolute pressure at inlet valves}\\ \text{P}_c=\quad ,, \qquad ,, \qquad ,, \text{ delivery } ,,\end{array}\right\}\text{lb. per sq. in.}$$

$$\therefore\quad \text{M.E.P.}=\frac{1{\cdot}25}{1{\cdot}25-1}\times 2\times 14{\cdot}7\left\{\left(\frac{114{\cdot}7}{14{\cdot}7}\right)^{\frac{1{\cdot}25-1}{2\times 1{\cdot}25}}-1\right\}$$

$$=5\times 2\times 14{\cdot}7(1{\cdot}2281-1)$$

$$=33{\cdot}53 \text{ lb. per sq. in.}=\text{M.E.P.}$$

The I.H.P. is then easily calculated by the well-known equation

$$\text{I.H.P.}=\frac{\text{PLAN}}{33000}\times 2,$$

except in considering cubic feet of air, whereas A is taken in square inches. Hence the volume

$$=2\times\text{stroke (feet)}\times\frac{\text{area of piston (sq. in.)}}{144}\times\text{R.P.M.}$$

But this is equal to the displacement; hence if it is considered as cubic feet per minute,

$$\text{I.H.P.}=\frac{\text{displacement}\times 144}{33000}\times\text{M.E.P.},$$

and as $\frac{33000}{144}=229{\cdot}166$,

$$\therefore\quad \text{I.H.P.}=\frac{\text{displacement}\times\text{M.E.P.}}{229{\cdot}166}.$$

Assuming the volumetric efficiency of the compressor at 90 per cent., the displacement will be equal to the capacity ÷ 90 per cent. $=\frac{\text{capacity}}{90{\cdot}0}$, the capacity being, of course, in cubic feet per minute.

$$\therefore\quad \text{I.H.P.}=\frac{\text{capacity}}{0{\cdot}90}\times\frac{\text{M.E.P.}}{229{\cdot}166}.$$

Then as the M.E.P. $=33{\cdot}53$. ∴ as $33{\cdot}53\div 229{\cdot}166=0{\cdot}1625$, I.H.P. $=$ capacity $\times\, 0{\cdot}1625$.

The I.H.P. required ∴ $=1000\times 0{\cdot}1625=162$. Assuming it to be steam-driven, with an efficiency of 85 per cent., the maximum horse-power required is about 200. For a gas engine this would be about 210 if the horse-power was reckoned on the indicator diagram, or about 170 if on the brake.

Again, taking into account the losses due to transmission, the maximum percentage of useful effect between air compressor and water cannot be taken at more than 30 per cent., assuming a direct-driven air compressor of 85 per cent. efficiency, 75 per cent. efficiency in compressing, 10 per cent. loss per mile on the main, which is the minimum that can be assumed when it is new and of the best construction, and 50 per cent. efficiency of the air motor. Then, if steam or other motive power develops 100 indicated horse-power at 1 mile from the compressor, the horse-power is equal to

$$100\times 0{\cdot}85\times 0{\cdot}75\times 0{\cdot}9\times 0{\cdot}5=28{\cdot}69\text{ H.P.};$$

or if the distance is half a mile,

$$100\times 0{\cdot}85\times 0{\cdot}75\times 0{\cdot}95\times 0{\cdot}5=30{\cdot}28\text{ H.P.}$$

The velocity of air in the mains must not exceed 40 ft. per second.

The coefficient of friction for the flow of air through wrought- and cast-iron pipes varies inversely as the diameter of the pipes, and is obtained by Professor W. C. Unwin's formula as follows :—

$$\text{Coefficient} = 0{\cdot}0027\left(1+\frac{3}{10d}\right),$$

where d is the diameter of the pipes in feet.

This coefficient is 0·00377 for 7½ in. diameter pipes.
„ „ „ 0·00449 „ 6 in. „ „

To obtain good results from a compressed-air motor, it is advisable in all cases where possible to reheat the compressed air up to 300° or 400° F., at a point near to the motor, the economy being increased, and difficulties with ice, etc., in the motor being removed.

Modern types of steam-driven air compressors will give efficiencies up to 90 per cent., a test on an Alley & Maclellan set giving 89·7 per cent. with compression at 100 lb. per sq. in. A recent test on a Reidler two-stage compression was carried out by Mr W. D. Hamilton, with the following results :—

	Per cent.
Efficiency of compression	95
„ combined engine and compressor .	77·8
Percentage loss due to friction of set . . .	9·2
„ „ in compression	4·5
„ „ due to clearance, radiation, leaks, and bends	8·5

Installations.—Before closing the chapter it may be well to say a few words on power-stations, or pumping-stations. The design of the pumping-station is a matter which might be entrusted to a municipal engineer, and it is important that he should be aware of a few of the essential principles underlying that design, so as to avoid costly and often practically unalterable mistakes. In the first instance, the site is the all-important question. It is of paramount importance to have such a pumping-station if possible near to a railway siding, canal side, or dock side, where coal could be landed with the minimum of trouble and expense. A sewage pumping-station will more often than not lend itself to such circumstances because of its necessarily being in a low part of the town. In a seaboard town this is particularly likely to be the case, as seen in the Ringsend pumping-station in Dublin, and the Salford and Manchester Corporation stations, both of which have access to the sea for import of coal and disposal of the sludge by the Manchester Ship Canal. Besides, such towns are usually so flat as to warrant a pumping-station.

It is important that the engineer should not be too ready to erect a pumping plant on a particular piece of land just because that piece of land happens to be cheap, or otherwise easy of acquisition, or because it actually happens to be a council's property. This latter consideration has unfortunately led engineers into difficulties too often. Again, water, both for feed purposes and condensing, must be readily obtainable. The subsoil, too, is an important factor. Piled foundations are expensive and not always satisfactory, although local requirements may very often demand their use. Then there are the smoke and, in the case of sewage works, the smell nuisances to contend with; and although these should not exist to any great degree in well-designed and well-managed schemes, objections will doubtless be raised if they do exist. Such matters all demand minute attention. It would be a very bad policy to place a station in a district where future extensions would be difficult and costly to provide for. To obtain a site, however, which is going to satisfy all these requirements is far from an easy matter. With gravitation mains, however, a central air-compressing station, by which would be worked a series of Shone's ejectors, could, within reasonable limits, be placed almost anywhere that conditions of transport of coal and water supply demanded.

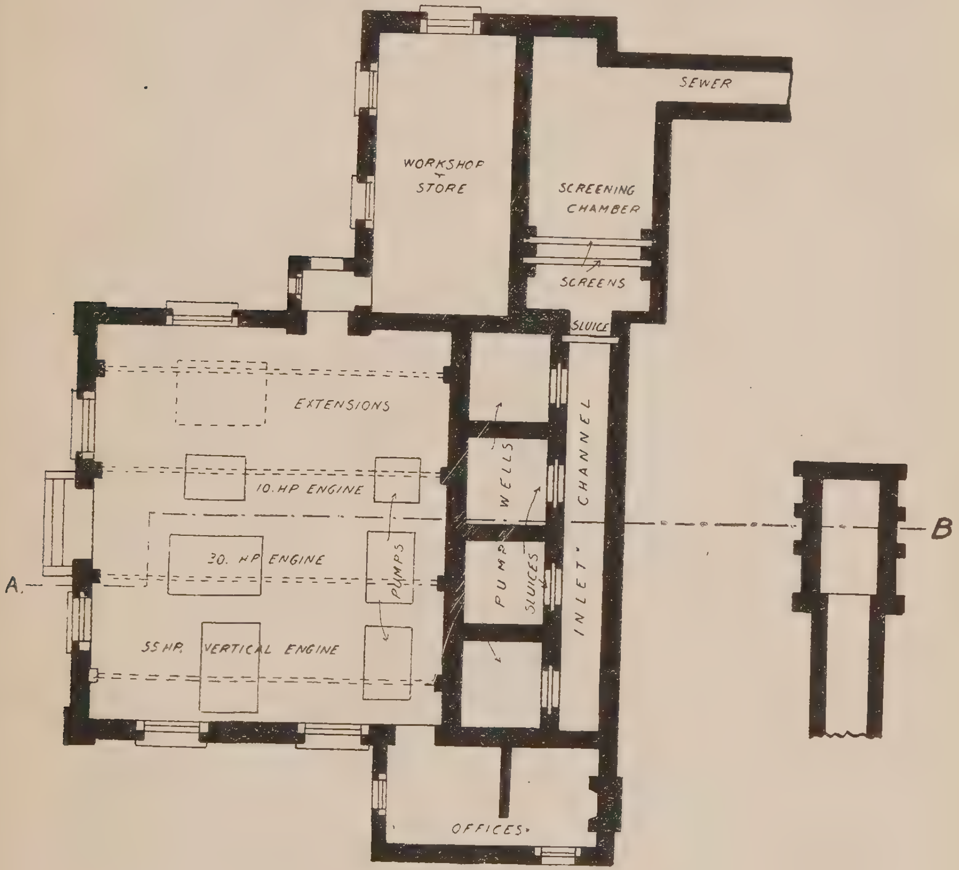

Fig. 235.

The main points to observe are:

1. Always provide for possible extension of all parts of the plant.
2. Engines and boilers should always be separate.
3. Feed pumps should not be in boiler-houses.
4. The fuel should be stored as near the boilers as possible, but not in such a position as there would be any risk of fire.

5. A workshop and stores should be provided.
6. Also an engineer's office, and, if a large station, a general and clerk's office.
7. A room and bath for the men will no doubt be appreciated.
8. An overhead travelling crane designed for a 10-ton load.
9. Ornamentation is not necessary on the exterior of power-stations.
10. The boiler-house would best be paved with brick on edge, and the engine-house with tessellated paving.

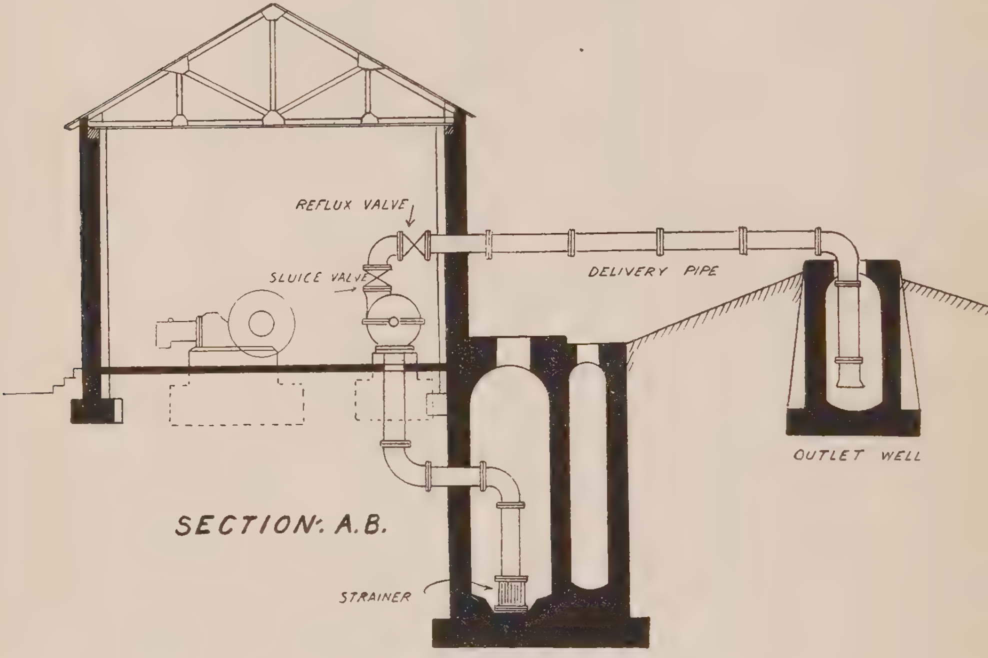

FIG. 236.

A very important observation is—not to place flues and economisers *below* the ground water-level. Water is sure to leak in, with continual reduction of economy.

With gas engines a good system of ventilation must be provided. It may have to be mechanical.

The gas-producer house should, however, always be separate, and the gas holders outside.

A typical small sewage pumping-station is shown in figs. 233 and 234, designed for the town commissioners of Morpeth and equipped by Tangyes.

A plan and section of the general arrangement of a station designed by the writer appears in figs. 235 and 236, in which there are two small and one large gas engine, driving centrifugal pumps and using town's gas.

For charging each of the pumps the apparatus is of the Gwynne-Sargeant patent type, which has been designed to provide a ready means of charging centrifugal pumps when a supply of steam for ejector is not available. It comprises a centrifugal pump, on the suction of which is an open water vessel placed above the pump, so that by filling the vessel the pump is charged. On the delivery of the pump is placed an air ejector (its vacuum chamber connected to top of main pump by suitable pipe), through which the whole of the water delivered by the pump passes at high velocity, and so forms a vacuum by induction in passing the nozzle. The water, after passing through the ejector, is discharged into the top of the water vessel, and so the same water is used over and over again until the main pump is charged.

The air is drawn from the main pump and pipes, issues with the water from the ejector, and is liberated at the open top of water vessel. The apparatus is driven by a belt from a pulley on the shaft of the engine, the velocity being as high as 1300 revs. per minute. A large air-compressing plant made by Messrs Hughes & Lancaster is illustrated in fig. 237.

CHAPTER IX.

HOUSE DRAINAGE.

It is surprising, when one reads about the large sums of money spent on laying down main drainage schemes every year for large and small towns, to find that the subject of house drains receives little or no attention from the engineer. The main reason may probably be looked for in the legislature regarding such drains, which does not demand any great degree of perfection in house-drainage systems. Local authorities, of course, have powers in the matter, but this appears to be confined principally to new work. When a new system of drains is laid down in a house, the owner or other responsible party is required to give notice to the local authority, who generally demand a copy of the plans, and themselves make the necessary connection with the main. Moreover, one of the engineers of the said authority makes it his business to test and supervise the work as it proceeds, and this generally will ensure good work. At the same time, the public do not care for too much interference; and the public officers, after all, are fully occupied with their essential duties, and have no time to give householders gratuitous advice; hence bad planning and arrangement are often allowed to pass. For instance, take the case of an old house. The drains may have been put in years ago, and the most serious state of affairs may exist in the house itself unknown to the inmates, who usually are confident that the system is quite perfect, and that they and their ancestors having lived there for years in good health is sufficient proof of their trust, till someone is suddenly stricken down with disease, and the medical adviser suggests the services of a sanitary engineer. Then the trouble begins: old built drains or open-jointed ones under houses are rooted up, bad ventilation, non-interception of sewer gas, old privies, pan closets, leaking soil pipes, and what not are suddenly brought to light. In such cases, what power has the local authority? The public resent the slightest interference, and unless someone *complains of a nuisance* to that authority, no steps on their part are taken to rectify the evil. Gradually, however, the public are waking up to the fact that house drainage is very important, but they are very slow to do so. A bad sewer may exist for years and do no material harm; if it leaks, the foundations of dwelling-houses are not usually affected; if it is badly ventilated, the only way the bad air can do harm is by the house drains. If the drains are good, such air cannot pass into them and do harm by reason of the intercepting trap: even if it did, the chances are that, the drains being tight and ventilated, it would find its way out rapidly through the ventilators. But suppose the system is bad, probably there will be no intercepting trap. The foul air from the sewer finds its way up leaking drains, which are often not properly laid and far too large for their purpose; under these circumstances they become cesspools. Gaining other foul air in its progress, it finds no means of egress by ventilators; but getting under the influence of a slight pressure, it readily finds its way into the dwelling through numerous channels. Under such circumstances it is indeed strange that there is not more sickness from this cause than there is.

Inspection.—The first thing which the reader should be acquainted with is the various forms of defective appliances to be found in bad house-drainage systems, and with the method of testing and reporting on them. Having this knowledge, he may turn his attention to designing and carrying out a new system according to the special circumstances of each case.

Supposing, now, that a system is reputed bad, and that the engineer is called in to inspect and advise upon it, he proceeds as follows: A sketch plan of the general arrangement, so far as it can be ascertained, is made, and all the information obtainable marked on it, such as traps, soil pipes, w.c.'s, air pipes, junctions, manholes, etc., and the approximate direction of the pipes. In old systems with very few fittings this latter will not always be easy, and the ground may have to be opened up in likely places.

The intercepting trap should be looked for, and investigated to see if it acts, as it should do, as a fresh-air inlet to the drain. This is usually a branch pipe carried to a garden wall, or the trap may simply have a rising piece to ground-level, with a galvanised grating on it. This rising piece should never be less than 9 in., or else it may be impossible to plug the drain for testing. The size of the drain must be ascertained: 4 in. is the best for a single house, 6 in. is the largest permissible; 9 in. and over, and all built drains, should be condemned. They are never self-cleansing. The open traps—that is, gullies, grease traps, etc.—should be looked at, and none but the simplest forms should be allowed. Bad traps usually cease to function in dry weather; moreover, they usually get very foul at the best of times; some bad traps are shown in the following illustrations:—

Fig. 238.—Bell trap.
,, 239.—Antill's trap.
,, 240.—Dipstone trap.
,, 241.—D trap; often found at the foot of soil pipes.
,, 242.—Running syphon trap.
,, 243.—Mid-feathered trap.

They need no description, and may be condemned without reserve. It should be ascertained if the scullery sink delivers outside into some form of grease-interceptor trap. Many engineers dispute the advantage of this appliance; the writer inclines to its use, because in practice grease has a habit of solidifying in the best of drains, and will often stoutly refuse removal by drain rods. It is now necessary to inspect the internal fittings. Starting with the lowermost floor, sinks will demand attention. Preferably these should be of white enamelled fireclay, with a 2-in. lead or iron trap, and overflow led outside to deliver into (not over) the back or side inlet of the grease trap below the grating or cover-head. Lined sinks are not satisfactory, but pantry sinks may, with advantage, be of teak. The house and yard w.c.'s should be good wash-*down* closets, with 2-in. flush pipes, and fed from $3\frac{1}{2}$-in.

galvanised cisterns.[1] Elaborate forms of combined cistern and closet are often found in houses. They are generally very satisfactory. Lead-lined, plug-valve cisterns, if in good order, generally serve their purpose well. All w.c. cisterns must have open-ended overflows, and should not supply water to any other part of the house. The awful forms of closet one comes across in even well-to-do houses is incredible. The wash-out closet, which was the forerunner of the wash-down, is not desirable. The depth of water is small; splashing occurs during the flush, and the front chips, gets porous, and rapidly becomes insanitary. The hopper-head closet is a bad form (fig. 244), but if in a yard w.c. and of the short type, with large water area and in good condition, not cased in, it may not be necessary to remove it. The engineer decides the question. No closets of any sort should be cased in: pan closets are the worst form; valve closets are not much better.

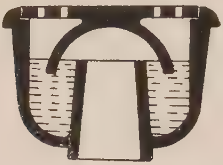
FIG. 238.

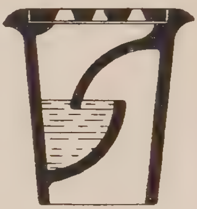
FIG. 239.

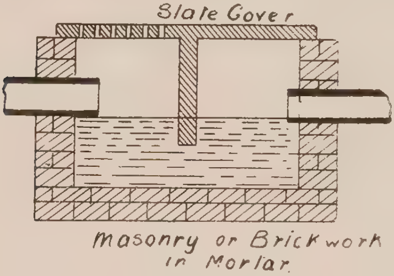

FIG. 240.

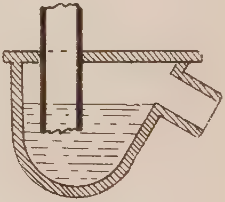
FIG. 241.

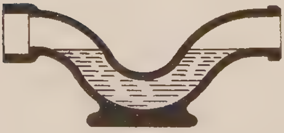
FIG. 242.

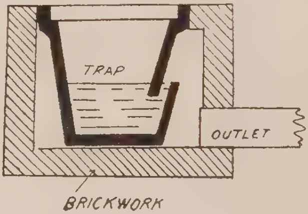

FIG. 243.

Why some firms are reintroducing this latter, which is complicated and very expensive, the writer fails to see.

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[1] In some towns the water may be so soft as to be injurious to galvanised cisterns. Enamelled fireclay or lead-lined wood cisterns must then be substituted.

Neither should baths be cased in. Such casings are quite unnecessary, and are receptacles for dirt, etc. The waste pipe should be trapped immediately under the bath; this, in the best patterns, is an integral part of the bath itself; in others it is a lead trap. If it is not visible, its absence may be proved by blowing smoke up the waste, or holding a match over the grating to ascertain if there is any draught through it. An overflow and a safe tray are essential. The latter should be made of sheet lead, and have an open-ended drip pipe like cisterns. No cistern or safe tray overflow must enter a waste pipe; the open end is sanitary, and serves to give warning when the overflow is in use, which normally it should not be. The bath waste is preferably a 2½-in. heavy-coated metal pipe, lead jointed; lead is often used, and is quite satisfactory. An independent bath waste pipe is much to be preferred to the practice of leading them into rain pipes. They should always enter a gully trap in ways to be described, and on no account be directly connected with the drain. The soil pipes should be rigorously inspected. The best type for all purposes is the 3½-in. or 4-in. heavy-coated metal pipe, fixed on to the outside walls by ear bands as shown in fig. 245, and delivering into a bend or soil-pipe shoe at the foot, and extending over the roof as a ventilation pipe. Inside soil pipes are most unsatisfactory, and a very strong reason should exist for allowing such a construction to remain. A trap is often found at the foot of soil pipes. It is quite unnecessary, except in special cases, which will be noticed. All light iron putty-jointed soil pipes must be removed. Similar pipes for bath wastes are far from the best practice. The bath waste should be continued over the eaves as a ventilation pipe, in the same way as the soil pipe; but, if no windows exist near, it may simply terminate a few feet above the highest branch. Slop-closets should be inspected under the same conditions as w.c.'s. They should have flushing cisterns and deliver into *soil pipes* only. The storage cistern should be examined, a point which is often overlooked, and the taps that it supplies noted. The bath is the only cold tap which should be so supplied; this is to ensure rapid filling; a ¾-in. pipe should be used. The main object of a storage cistern in towns having a constant high-pressure supply is to feed the hot-water system. The other taps, from which drinking water may be drawn, should be directly off the rising pipe to the main cistern; this also applies to w.c. cisterns. Of course, in places where the supply is

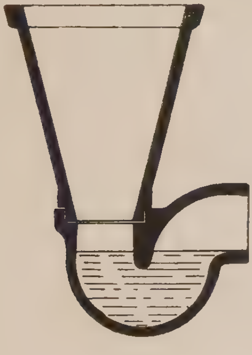

Fig. 244.

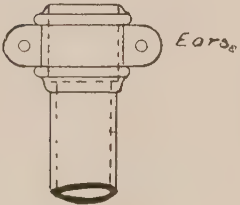

Fig. 245.

not constant, these regulations must be relaxed. For ordinary houses, a cistern 3 ft. 6 in. × 3 ft. 6 in. × 2 ft. 6 in. is quite large enough.

There is not much to choose between galvanised iron and wood lead-lined. A cistern should always have a cover and a 1-in. open-ended overflow. It is surprising how dirt finds its way into uncovered cisterns, to say nothing of dead mice and rats.

Testing.—Having thus inspected each fitting in the house one by one, and noted its form and condition, the tests must be applied to the drains.

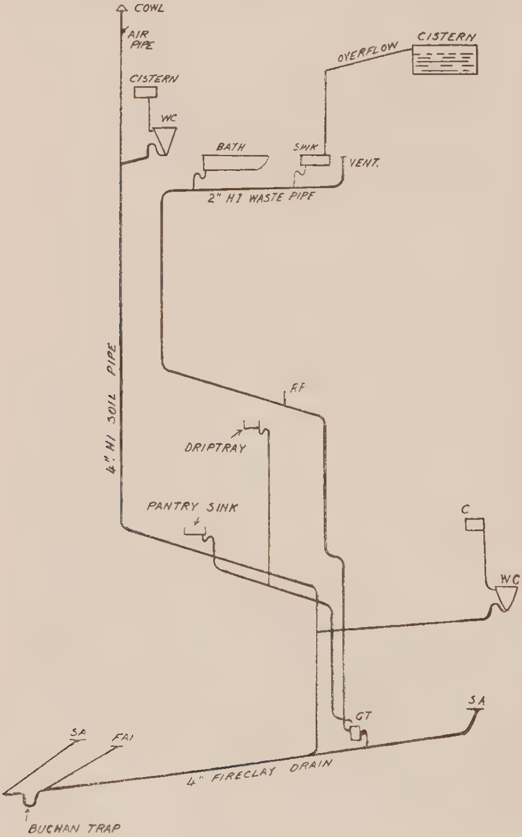

Fig. 246.

First, the water test. If the drain has an interceptor trap, insert a screw or bag plug in it *up* the drain. When the rising piece of a Buchan trap is only 4 in., this is often impossible. The lowermost inspection eye must then be selected, and a note made that a certain part of the drain could not be tested. All the available water should then be turned into the drain till the water rises as high as convenient in a trap or inspection eye. Then turn off *all* water and watch if the level stands steady. If so, all well and good. If not, it may be well to open up the drain at a shallow point to ascertain its condition and method of jointing; besides, a leaky drain will usually be wet underneath. It should be stated in the report if, and where, the drain was opened. Each separate section of drain will have to be plugged off, filled, and tested. It does not always happen that all the drains will fill up at one plugging, owing to the fall. The soil pipes and w.c.'s must now be subjected to the smoke test. For this purpose special machines are made. The writer uses Burn & Baillie's, and finds it most satisfactory. If there is a special shoe at the foot of the soil pipe for the purpose, the cover is lifted and the tube of the smoke machine inserted, the drain immediately below this shoe having previously been plugged off downhill, in order to prevent smoke being wasted on the drain. Having made a tight connection, smoke is pumped into the soil pipe. The writer provides small lead flanges of various sizes, 12 in.

×12 in. to 4 in.×4 in., for this purpose, having a hole cut in the centre for the smoke machine pipe. This flange is placed over the soil-pipe shoe; or if this does not exist, over a gully or inspection cover. The former must be emptied of its water previously. A little mud or moist earth makes quite a satisfactory smoke-tight joint. When a gully trap is used, a plug must be inserted in the interceptor to keep the smoke out. Smoke may now be pumped till it issues at the soil-pipe ventilator. This will prove that it is not choked; if choked, as is often the case, no smoke will appear. If clear, it must be plugged; and when a good pressure of smoke is on, the inspector must go to every closet and slop closet for the purpose of looking and searching for smoke, especially at the joint between closet and soil pipe, as this is often very defective. The joints of the soil pipe, especially if internal, should be looked to. Care must be taken not to apply too much pressure, or else the seals of the w.c. traps will be forced, but a gentle pulsation of the water in the traps proves the efficiency of the process.

Reports.—Having thus got all the information possible on the system, a report of the results will generally be required. This should be clear and to the point, every detail being separately considered, but without unnecessary wording. Above all, the reader should remember that such reports usually find their way into the hands of people who are not engineers; therefore the language should be as free from technical terms as possible. All reports should have a block plan of the house showing the drains; a diagram section of the form shown in fig. 246 is also very useful. The form of report usually adopted by the writer is as follows:—

Report No. ......

Name and Address of Engineer who is making Report ....

Premises reported upon ....

On the ...... inst., an examination was made of the above premises with reference to the sanitary arrangements, and I have to report as follows:—

The house soil drain starts from ...... and passes through ...... and onwards to join the public sewer in ...... street (or cesspool or other outlet).

It is formed of ......, and the joints are made with ...... (If it was not necessary to open up the drain, state so here.) It was ...... in working order.

The drains are ...... through ventilated and ...... well planned. (State any other particulars, such as stable drains, etc.) The open traps are of ...... reliable description, and are clear (or choked). The scullery drain is trapped (or not) from the main system.

The system is trapped off from the public sewer (or cesspool) at ...... by a ...... trap. (State pattern or maker's name.)

The soil pipe is a ...... one, ... properly jointed, and ...... carried full bore ...... feet over the main eaves and terminating with ...... (State if cowl or wire netting, etc.) The bath waste is a ...... one ...... properly jointed. It has ...... a ventilator in the form of ...... The bath is a ...... one and ...... trapped inside ...... properly. The waste is ...... trapped off from the system at ground-level by a ...... trap. (State form of trap.) The house w.c. is ...... and the yard w.c. ...... The cisterns are ......, the flushes are ...... good, and the cisterns have ...... open overflows. They are in good (or bad) working order. The scullery sink is a ...... one, and the pantry sink ...... one; they have

...... properly trapped wastes, and the scullery has ...... a grease trap of good (or bad) form. (Describe here any other sinks or slop-closets.) The storage cistern is ...... one, and holds about ...... gallons (6¼ gallons in one cubic foot). It has ...... a cover and a ...... proper overflow. The draw-off cocks are supplied from (state if main or cistern). Drinking water may be drawn from the one off the main in ...... (stating any taps direct off the main).

The hydraulic test was applied to the drains with the following results: .... The smoke test was also applied with results as follows: .... In order to render the drainage and sanitary arrangements of this house satisfactory, it would be necessary to carry out the following recommendations: ....

The reader will now, from perusing the following pages, see what should be done, and he must use his own judgment in the recommendations he makes.

Where there appears to be no interceptor trap, continual pumping of smoke into the drains may reveal its absence by smoke rising out of the street manholes.

Planning New Drains.—After the existing work has been described, the work necessary should be stipulated which will make the system in perfect order. Where this is only small it is well to include it in the report in such a manner that any contractor will be able to carry out the work accordingly without further instruction. When the work is extensive it is better to state that certain work is required, and that a full specification and drawings will be drawn up if required. This will save the engineer unnecessary trouble if his client does not accept his advice—a very frequent occurrence. The planning of the drains demands more attention from experienced persons than will at first be supposed. Bad or faulty design may be the cause of waste of money. The main points to bear in mind are:

1. All drains must be in true straight lines from point to point.
2. They should be laid with the greatest available fall, which should be evenly distributed.
3. Each house system should be separated from those of neighbouring houses. This is a very important point, because if the drain takes the sewage from several houses it becomes a common drain. After a time, if this drain happens to want repair, it is very difficult to find anyone who will be responsible, while in most cases the local authority will disclaim any responsibility in the matter. This question has given endless trouble in the law courts, and no decision seems yet to have been arrived at in the matter, although a movement is on foot to try and establish a satisfactory legal definition of "Drain" and "Sewer." The matter is returned to presently.
4. Each house system must be separately trapped off from the main sewer or cesspool by one of the forms of interceptor trap to be described.
5. Junctions should, as far as possible, be grouped together in special junction pieces known as "Armstrongs," which have raising pieces to surface-level and galvanised covers.
6. All drains should be through ventilated by means of an air-inlet pipe at the interceptor trap, and a continuation of the soil pipe above the eaves of the house as an outlet ventilator. This system will induce a slight constant current of air through the drain, but the soil pipe may not be at the head of the drain. In this case, although that pipe must be ventilated *full*

bore, at the head of the drain a 4-in. heavy-coated metal pipe should always be run up the house, just like a soil pipe. Drains must under no circumstances ventilate into rain or waste pipes. Again, if the system is large, it may be better to have two or more sections, separately trapped off, and ventilated on their own account, as shown in figs. 248, 249, and 250.

7. Only wash-down pedestal (or syphonic) closets are admissible in new work.

8. Scullery sinks must have traps inside the house, and deliver into grease traps outside of it. Baths and basins must likewise be trapped inside, and deliver by ventilated waste pipes into gullies outside.

9. All gullies should be set in concrete and be of the simplest possible form. In large town buildings, gully traps may be required in the basement to take waste pipes. They must then have close covers.

10. Rain pipes must never enter a drain direct, but *over* the grating of some forms of gully trap.

11. Sweeping arms should be placed at the heads of all long drains or branches.

12. The use of manholes in house-drainage work is not always necessary; architects often provide far too many. Where, however, the interceptor is over 6 ft. deep, it is well to place a manhole at this point; also where the level of two sections of drain change abruptly, as in cases to be pointed out.

13. The size of a house drain demands attention. The old practice of using 12-in. and built drains was ridiculous. Such drains are never self-cleansing. As before stated, a 4-in. drain is usually ample, 5-in. and 6-in. being used at the engineer's discretion. They should be laid on a bed of concrete, as described under Sewers, and packed up underneath between the sockets with similar concrete to take the load off the joints. The joints are made with gaskin and cement, but the Stanford joint is very much to be preferred. It has already been fully described. Under houses, all fireclay drains must be covered with 6 in. of concrete. Iron drainage will be discussed later on.

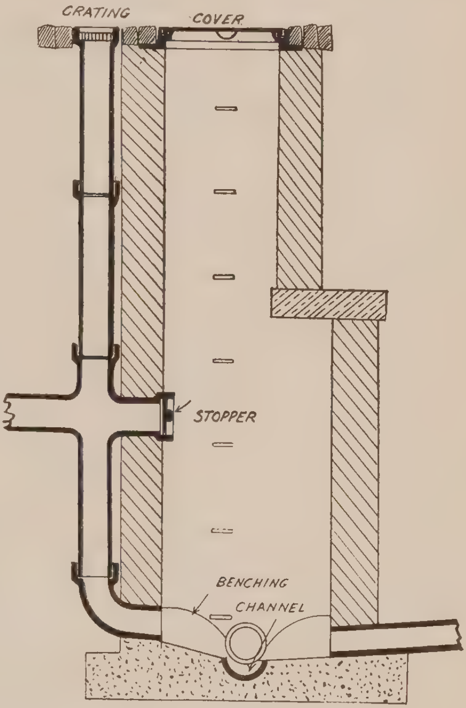

FIG. 247.

14. Soil pipes should be 4-in. heavy-coated metal, lead-jointed pipes. It is well to specify the weight of such pipes per yard, because there are now on the market pipes of this kind which are merely rain pipes with a heavy-*looking* socket, and really not heavy-coated pipes at all. Lead soil pipes are

not to be advised; and although engineers differ on this point, the writer still adheres to the iron pipe, as, with the various stock bends, offsets, etc., they can be conveniently placed in the most awkward positions.

15. House drains should have a good fall; 1 in. in 10 ft. is about the maximum, 1–36 is a good average, but in many places it will pay, by reducing excavation, to drop drains having a very stiff fall vertically a few feet, at convenient points, by means of a cascade pipe of the form shown in fig. 247.

The following reference lettering is generally used on plans:—

MH=manhole. Ap=air pipe (outlet).
IT=interceptor trap. FAI=fresh-air inlet.
GT=gully trap.
SA=sweeping arm.
AJ=Armstrong junction.
SP=soil pipe. RP=rain pipe. WP=waste pipe.
S=sink.
TGT=turret grease trap. C=cascade.

In fig. 248 is shown an example of the drainage of a large country mansion, in which there are two high-level drains and one low-level one, for draining the basement and other purposes, into which the former enters by means of cascade pipes.

In fig. 249 is shown an example of a large city building with only a very small open space, in which the soil and waste pipes had to be for the most part inside. Other examples, of course, present themselves in practice, very few being similar to the two cases shown in figs. 248 and 249.

Drains and Sewers.

What actually constitues a drain or sewer is one of the most debatable questions of modern legislature, so diverse are the opinions of legal experts. The following is a typical example of this controversy:—

Building Estate—"Drain or Sewer"—No Use of Pipes—Whether User necessary to constitute a Sewer.

This was a motion for a declaration that a line of pipes laid by the plaintiff in a portion of his land, which he had laid out as a road, was not a sewer vested in the defendant Council under the Public Health Act, 1875, or otherwise; and that the defendant Council was not entitled to connect any sewer with such lines of pipes; and for an injunction restraining the defendants from trespassing and making such connection. The sewer or drain had been constructed by the plaintiff in accordance with plans and specifications deposited with and approved by the surveyor to the Council, and to the satisfaction of the Council, who admitted they were liable for its repair. The plaintiff was developing a building estate, but at present there were no houses on this particular road, and no drainage had hitherto passed down the pipes in question, which were connected at the east end with a sewer constructed by the plaintiff, and now vested in the defendants. The defendants had served a notice on the plaintiff expressing their intention of connecting a sewer which was vested in themselves, and which ran from the west end of the road, with the pipes laid down by the defendant, at the point where their sewer reached the plaintiff's pipes at his boundary in the road; and they alleged that the pipes in question were a sewer vested in themselves. The plaintiff was apprehensive of damage being done to his land by the exercise of the alleged rights of the defendants over the sewer or drain. The definition of a "drain" by section 4 of the Public Health Act, 1875, is "any drain of

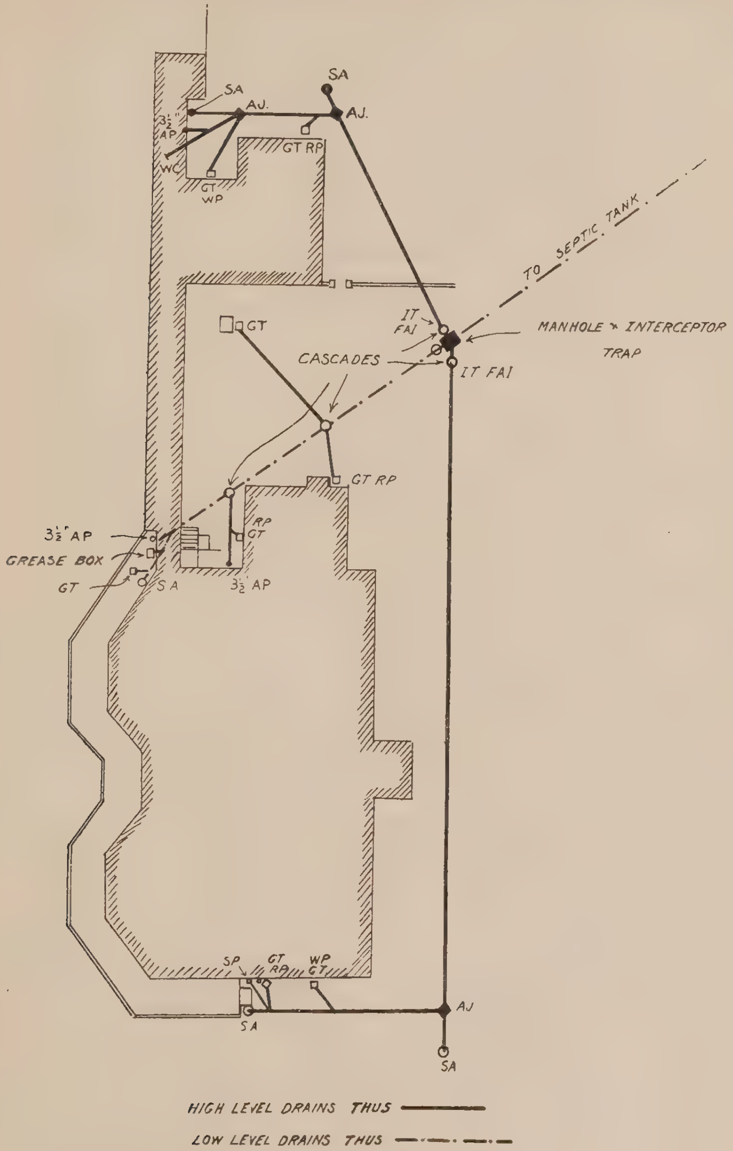

Fig. 248.

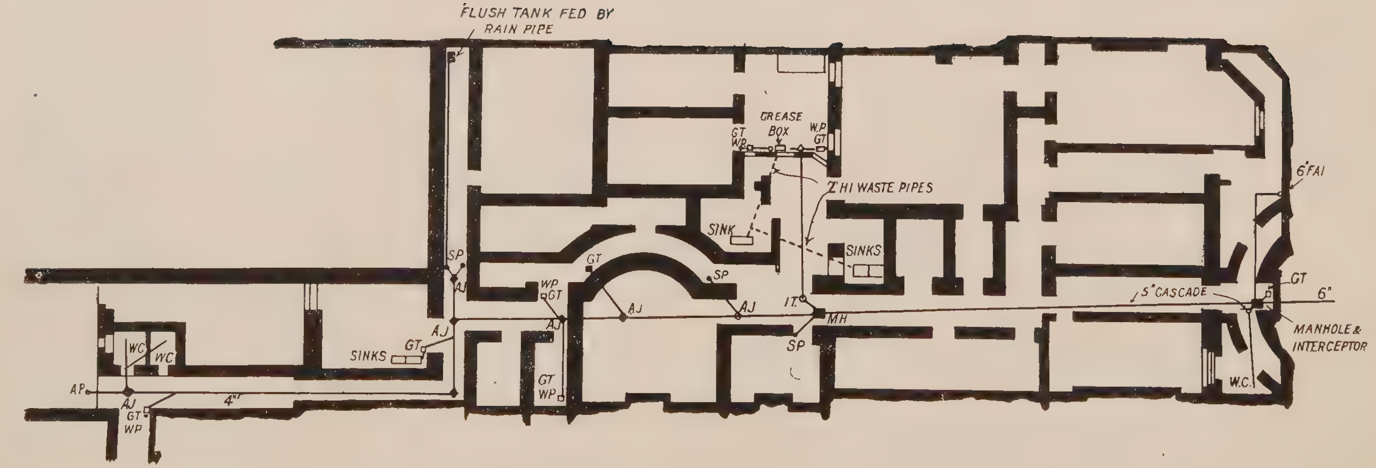
FLUSH TANK FED BY RAIN PIPE
GREASE BOX
GT
WP
W.P
GT
2"HI WASTE PIPES
6"FAI
SINK
SINKS
SP
AJ
GT
WP
GT
SP
AJ
AJ
IT.
MH
SP
5"CASCADE
GT
6"
MANHOLE & INTERCEPTOR
W.C.
WC
WC
AP
AJ
GT
WP
4"
SINKS
GT
AJ
AJ
GT
WP

Fig. 249.

and used for the draining of one building only, or premises within the same curtilage, and made merely for the purpose of communicating therefrom with a cesspool, or . . . . with a sewer into which the drainage of two or more buildings or premises occupied by different persons is conveyed. 'Sewer' includes sewers and drains of every description, except drains to which the word 'drain' interpreted as aforesaid applies." By section 13 : "All existing and future sewers within the district of a local authority, together with all buildings, works, materials, and things belonging thereto, shall vest in and be under the control of such local authority." It was contended for the plaintiff that a pipe which did not drain anything was not a sewer, and that there must have been user ; that to hold that the pipes were a sewer would impose a liability under section 15 on the local authority to repair any pipe laid down in a building estate ; and that the case turned on the question whether the local authority were satisfied with the street as sewered. It was contended, *contra*, that it was impossible to say the street had not been sewered, having been laid out under the Council's supervision ; that there had been no obligation on the plaintiff to do the work, but that the work, if done, had to be in accordance with the Council's plans ; that directly a sewer is made it vests in the local authority ; that in Hornsey Local Board *v.* Davis it was held that, although a sewer had never been used, the road was sewered to the satisfaction of the local authority ; and that here the Council were satisfied at any rate with the sewer, if not with the street.

The Court decided that it could not grant the application, but that the matter in issue would have to be decided at the time of the action, the costs of the application to be treated as part of the costs of the action. The question is one of considerable importance.

It is necessary to draw attention to the present unsatisfactory state of the law on the question as to what constitutes a "drain" and what a "sewer," and to refer to the Bill introduced into Parliament to amend the Public Health Acts Amendment Act, 1890. That Bill is necessitated owing to the difficulties created by section 19 of this Act, as shown in a number of cases during the past few years, which led to strong expressions of opinion by the judges as to the desirability of an amendment to remove the anomalies caused by a strict interpretation of section 19. Prior to that Act the definitions of "drain" and "sewer" were fairly clear. Thus section 4 of the Public Health Act, 1875, defines these terms as follows : "'Drain' means any drain of and used for the drainage of one building only or premises within the same curtilage, and made merely for the purpose of communicating therefrom with a cesspool or . . . . with a sewer into which the drainage of two or more buildings or premises occupied by different persons is conveyed, and 'sewer' includes sewers and drains of every description except drains to which the word 'drain,' interpreted as aforesaid, applies. . . ." No practical difficulty in applying these definitions arose where houses were separately drained into a sewer, but the definition did not cover the case of a system of combined drainage of several houses, whether belonging to the same or different owners. To remedy this defect section 19 of the Act of 1890 was passed, which contained the following provision—viz. that where two or more houses *belonging to different owners* are connected with a public sewer by a single private drain, an application may be made under section 41 of the Public Health Act, 1875 (relating to complaints as to nuisances from drains, under which the expense of repairing drains may be thrown on the owners of such drains. It will be seen that this definition does not cover the case of a combined system where the houses belong to the same owner. This absurd result followed, that in the latter case the drain was a sewer, repairable, etc., by the local authority, while in the case provided for by section 19 the drain was a drain, the repair of which might be thrown on the owner. This anomaly was revealed in the cases of Thompson *v.* Eccles Corporation, Jackson *v.* Wimbledon Urban District Council, and Hardwicke *v.* Friern Barnet Urban District Council, all reported in *Law Reports*, 1904, 2 K.B.; Bradford *v.* Mayor, etc., of Eastbourne, 1896, 2 Q.B. 205; and Wood Green Urban Council *v.* Joseph, 1907, 1 K.B. 187. To cure this anomaly is the object of Mr Vivian's Bill, which provides that a pair or group of houses owned by one person is to be treated in the same way as if owned by different persons—*i.e.* where they connect with a sewer by a private drain the latter will be treated in all cases as a drain repairable by the owner, and not as a sewer, within the meaning of section 4 of the Public Health Act, 1875.

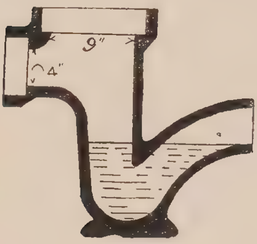

FIG. 250.

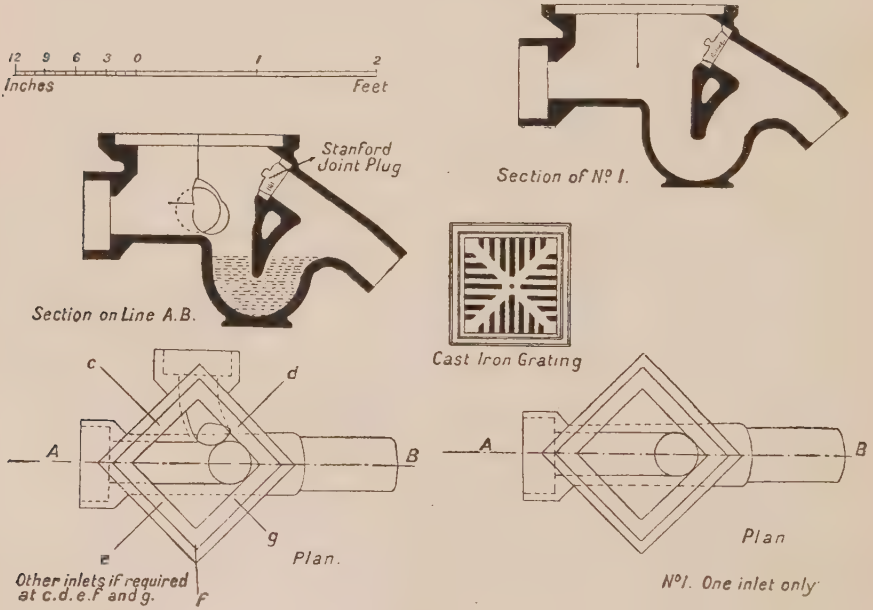

FIG. 250A.

Appliances—The Interceptor Trap.—Starting with the all-important interceptor trap, there are two forms in use which are most favoured.

Fig. 250 shows what is known as the Buchan trap, which, for depths up to 6 ft., is most satisfactory. The raising piece need not act as the air-inlet, but may have a close cover and a 5-in. branch to a more suitable point.

In fig. 250A is shown another form of interceptor trap, not unlike the

Buchan trap. It combines the well-known Buchan trap with the Armstrong junction, and can be had with various inlets as shown, and for shallow depths is much cheaper and preferable to a manhole chamber. The stopper is of the ordinary Stanford joint pattern, but a heavy screwed cap and frame is also supplied as a substitute at a small extra cost.

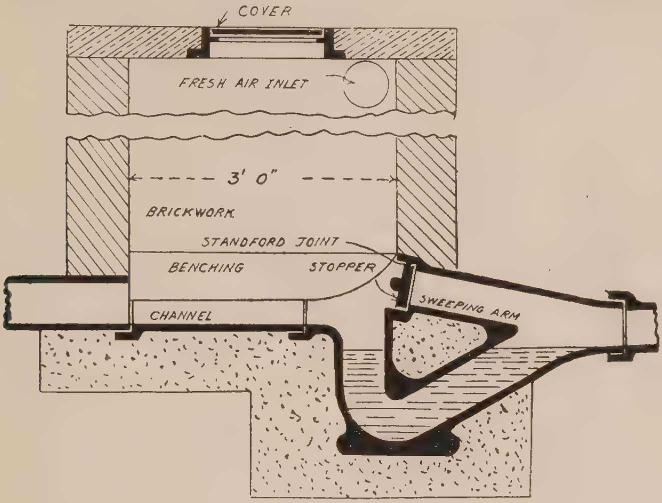

FIG. 251.

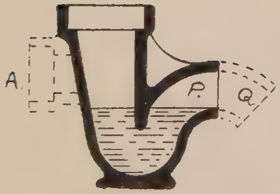

FIG. 252.

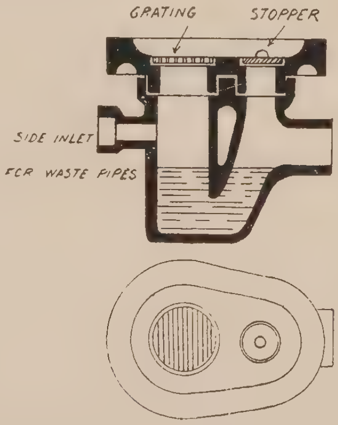

FIG. 253.

For greater depths it is preferable to sink a manhole as in fig. 251, and place in it a Broad's trap. The channels and trap should be white glazed for preference. A great advantage of this trap is the sweeping arm to the cross drain. It should have a Stanford joint stopper, and it is important to see that this stopper is quite tight when inspecting the drain, or else the interceptor trap fails in its purpose. The manholes may be built in brickwork, in cement mortar, or 12-in. concrete. It is a mistake to make them too small, or else a man clearing a choked drain (which is one of the purposes of a manhole on house drains) cannot work properly. 2 ft. 6 in. × 3 ft. 6 in. is a good size, or a 3-ft. square chamber, with the drain running from corner to corner; a galvanised cover of a weight suited to the traffic passing over must be provided. All such covers must be made tight in their frames with grease.

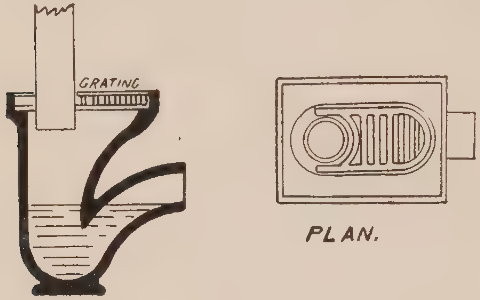

Fig. 254.

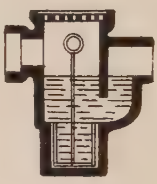

Fig. 255.

Gullies.—There are various types of gullies on the market. Some claim special advantage, which will be apparent to those who inspect them. The simplest forms are, however, the best. For draining surface water the type shown in fig. 252 is satisfactory. This type may also have side or back inlet branches for taking waste pipes, and may also be used under rain pipes. For rain pipes, however, the writer has found the most suitable trap to be that shown in fig. 253, known as the Board of Works pattern, of which the sweeping arm is often an advantage, while the large tray makes it a very convenient form. This trap may also have a side or back inlet branch for waste pipes. For bath wastes, however, a convenient trap is Hart's (fig. 254), into which the waste simply enters vertically, and so saves bends.

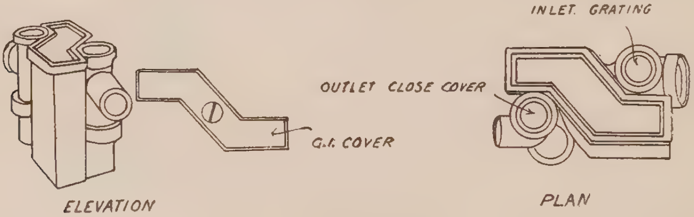

Fig. 256.

Grease Traps.—Gully traps are not suited to sink waste, as they do not intercept the grease from the drain. For these, some form of grease trap should be substituted. The most popular appears to be Dean's (fig. 255), but the cooling surface is only small, while they often want cleaning if much grease goes into them. For large houses, a better form is that known as the Turret grease box (fig. 256). It has a large cooling surface, is easily cleaned, and, moreover, will fit in most awkward places without much inconvenience, as the inlet and outgo are capable of being turned through a large angle. The stopper to the outlet must be set tight to stand the smoke test.

Water-closets.—The general arrangement of a water-closet, cistern, and soil-pipe connections is shown in fig. 257, and the closet is what is known as the wash-down form. This is the form which is now considered to be the simplest and most sanitary, and is not likely to be readily improved upon; moreover, its simplicity causes it to be quite cheap, which is a great point in its favour.

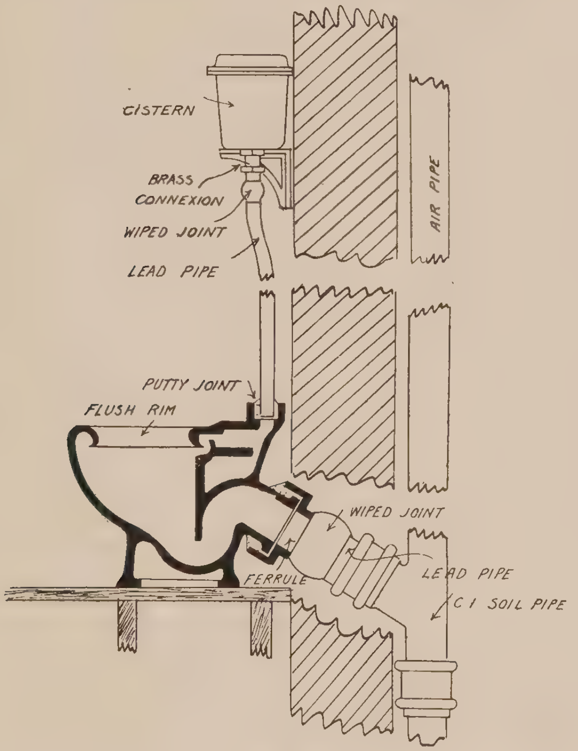

Fig. 257.

There is a modification of the above form in what is known as the syphonic closet, which merely consists of a wash-down pattern of special form, and another syphon trap, immediately following the closet basin trap. The advocates claim that this second trap causes a partial vacuum in the first, and so lowers the water-level considerably during flushing, and draws away any solids which might be left after the first flush. The closet does all that it claims to do, and in towns where the size of the cistern is regulated to 3½ gals. or so, it is useful. Particular attention is drawn to the joint between the closet pan and soil pipe. It is very often defective, and must be made to stand a very severe smoke test. There are various ways of making this joint. The most usual is by means of what is known as a

County Council ferrule (being the pattern originally recommended by the L.C.C.). It consists of a brass cup-shaped casting (fig. 258), into which the closet outgo pipe is placed, and the joint made with Medina cement at one end, the other being sweated on to a short 4-in. lead branch pipe. This branch pipe passes through the wall and enters a branch of the soil pipe. It has a brass flange sweated on to it, which holds it firm, when the joint is run with lead in the usual way. Altogether the joint is very satisfactory, but a great improvement has been made by a friend of the writer's, Mr T. J. Keating of Dublin, in the form shown in fig. 259. The inventor claims that by his system the closet may be removed without damaging the connection, because the joint is run up with a molten composition which can be melted out by an ordinary blowpipe. The other connection is the same as for the County Council ferrule. It may be noted that the design is such that none of the jointing composition can fall into the pipe, as it would overflow outside before that could happen. It is most important that this particular work should have minute attention on the part of those carrying it out, and that the inspection be made rigorously. There are more defects in this joint than in any other in house-drainage systems.

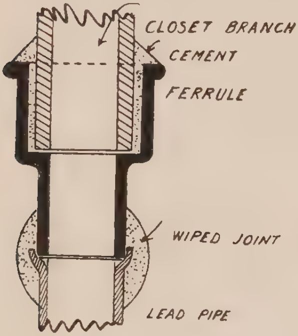

Fig. 258.

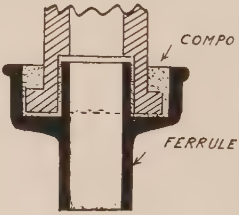

Fig. 259.

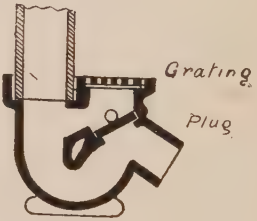

Fig. 260.

Ground-floor closets, where possible, should be fixed into an upturned fireclay or iron bend of the drain pipe. The joint should be made *above* the floor-level, so as to be easily seen. It is also quite possible to cement a closet having a " P " trap direct into a branch of the iron soil pipe carried through the wall, if those pipes are of a heavy quality, with, consequently, large sockets. The system is quite satisfactory. Messrs Doulton & Co. have a special type applied to their own closets. It is known as the Metallo-Keramic Joint, and is a patent. The idea is to weld, by their patent process, the lead branch to the soil pipe on to the closet pan, and this is done quite successfully. The soil pipe must continue of full bore right up the side of the house, to 3 ft. over the main eaves. It is best carried outside the gutter by an offset bend, but many cut through the cantilever of the roof. Hunter's cowls are usually provided at the top, but they have the disadvantage of being selected by birds for nesting-places, which chokes the pipe. A much better system is a simple bell-mouth, with a galvanised grating in it. The Hunter's cowls, however, have the nicest appearance. Slop sinks must deliver into soil pipes, or be treated in the very same way as closets, and have regulation flushing cisterns. When a building is high, and has many closets as well as slop closets going into the same soil pipe, a sudden rush of water at the top may syphon the traps of the lower ones. It is in this case that a trap at the foot of the soil pipe (fig. 260) is advisable, but in this case only. It may, however, be deemed more advisable, especially if expense is not restricted, to use closets having a special 2-in. branch pipe on the top of the outgo trap, known as an anti-syphon pipe,

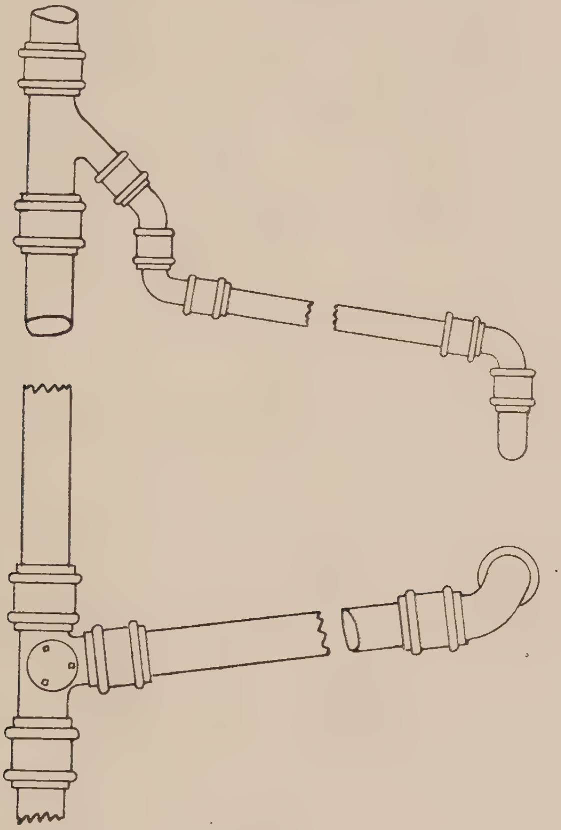

FIG. 261.

from which 2-in. heavy-coated metal pipes are carried up the side of the house, as shown in elevation in fig. 261. The ordinary form of soil-pipe shoe, recommended for testing purposes, is shown in fig. 262.

Sinks and Scullery Troughs.—These appliances are best made of white enamelled fireclay of a size suitable to the duty expected of them. The trap should be placed immediately under the sink, and in good-class houses may be of drawn lead with cleaning eye of brass and 2 in. internal diameter. For tenements and places where a lead trap may be stove in with a blow, 2-in. cast-iron traps are much more suitable. A brass grating, plug, chain, and overflow (the latter as an integral part of the sink) completes the apparatus. Sinks must be open underneath, and may be supported on brick walls, fireclay ornamental pedestals, or tee-iron cantilevers built into the main walls. A fluted teak drainer must be provided. The waste pipe of 2-in. heavy iron, lead-jointed, is run to the nearest grease trap. If this pipe is long it should be laid above the floor and hooked into walls, cleaning plugs being provided at the ends of each straight run. Pantry sinks are best made of teak, but are treated in precisely the same way as scullery sinks. The waste pipes should be continued above the highest branch, in the same way as soil pipes, for ventilation, but need not necessarily be carried over the eaves.

Junctions in House Drains.—House drains are laid in exactly the same way as pipe sewers already described, so no more will be said on the subject beyond the fact that no square junctions should be permitted at all; at bends and junctions (unless the branch is a very short one), Armstrong junctions of the form shown in fig. 263 should be provided. At the head of all straight lines, a sweeping arm of the form shown in fig. 264 should be placed at surface-level, with the stopper set in *mortar* to ensure its easy removal in case of a stoppage. When Buchan traps are used, it is also useful to bring a branch from the cross drain to the surface-level, and terminate with a sweeping arm of a similar type. Fig. 265 shows an anti-flooding trap which may be required in low-lying houses with deep basements.

Baths and Basins are usually chosen by the owner of the house. They must have traps inside, deliver into heavy-coated metal 2-in. or 2½-in. waste pipes outside, which, in turn, deliver into a trap at the foot. No casings should be permitted, as they are useless, harbour dirt, and hide leaks.

Lead Soil Pipes.—These pipes are not considered so satisfactory as heavy-coated metal, for many reasons, but in the case of old artistic mansions are considered by many as less unsightly than iron ones, and may be used under very exceptional circumstances. They must serve as clear ventilators in the same way as iron ones, and should be 3½ to 4 in. in internal diameter the whole way up. The lead used should weigh 10 lb. per yard, and the pipe be solid drawn. Lead pipes are much more liable to faulty workmanship and damage in use than iron ones, and should consequently receive very minute supervision. In figs. 266–268 are shown three very imperfect joints, much beloved by unscrupulous plumbers, but not suited to the ethics of modern sanitary science. The only joint which can be tolerated is the wiped joint (fig. 269).

Iron Drains.—It must not be supposed that in this chapter all the numerous fittings made for house-drainage work have been described. A selection has been made of those which appear best suited to the duties assigned to them, and the essential features of any ordinary house-drainage scheme likely to occur in practice have been described. The reader cannot do better than refer to the makers' catalogues for particulars of all the various special appliances on the market, but he should always beware of anything of a complicated nature. The subject of sewage disposal, applied to country houses, will be discussed in a later chapter; in the meantime attention is drawn to the subject of cast-iron drainage. There is no doubt that for durability under all conditions cast iron offers much greater advantages than fireclay. It is surprising how little attention it has had, considering this, and also the fact that, although more expensive than fireclay, it may be cheaper in the end. Cement joints, however well made, are never a certain quantity, and failure often occurs after ten years or so. The Stanford joint has done much to mitigate the evil, but for drains under houses cast iron should be used without reserve. When a leak is found in a house drain outside the house, and the leak is very small, it may not be deemed necessary to relay the drain, since a pipe under the full pressure of a test leaks much more freely than under ordinary circumstances, and the practice of opening up a drain and patching up the joints is unsatisfactory and nearly as expensive as relaying. Under a house, however, the slightest leak is a good reason for relaying, which is naturally an expensive

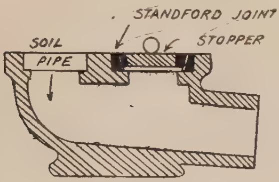

FIG. 262.

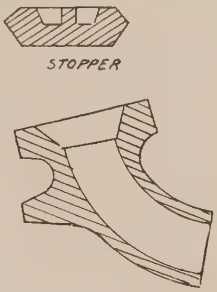

FIG. 264.

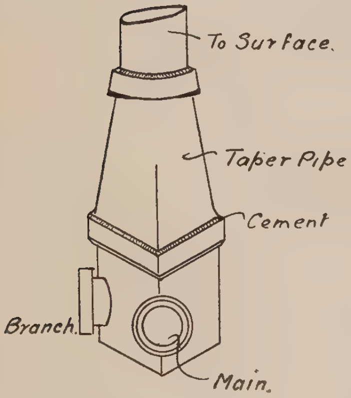

FIG. 263.

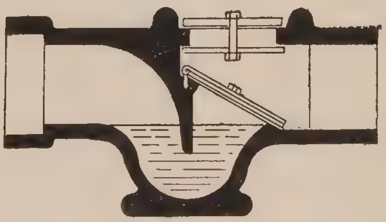

FIG. 265.

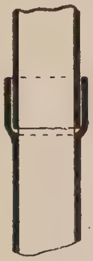

FIG. 266.

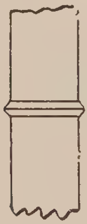

FIG. 267.

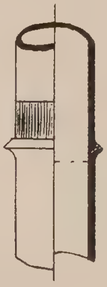

FIG. 268.

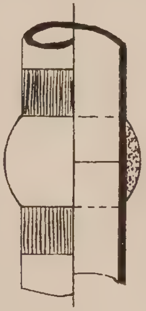

FIG. 269.

and a very inconvenient upset to the inmates. If iron had been put down originally, the chances of failure would have been very remote. The writer has tested cast-iron drains laid down for as long as forty years and found them perfectly sound under 20 ft. of water, the pipes inside being clear and hardly corroded. The invert was clean and metallic. The pipes should always be very heavy, the required weight per yard being specified,[1] and also the head to which they are to be tested. They should be obtained from firms who make pipes specially for this purpose, as they are made very smooth inside. 9-ft. lengths are used for straight lines, which reduces the labour on jointing, but shorter lengths are sold when required. Glass enamelled pipes are certainly very much to be desired, as they have a smooth, uncorrodible surface. They have the disadvantage, however, of crazing when cut, which seems to induce corrosion at or near that point; and this, together with the fact that pipes coated with Angus Smith's solution (all ironwork of any kind in drainage work, unless galvanised, must be so treated) satisfy all conditions, seems to cast a doubt as to whether the extra expense is justified.

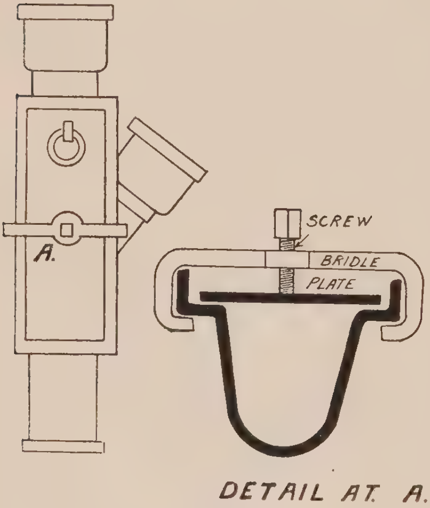

Fig. 270.

Most of the surface and intercepting traps, with splay and square junctions and bends, found in fireclay and stoneware, are to be had in cast iron, but it is usual to find interceptors and gullies made in two parts. Bends and junctions also usually have cast-iron covers screwed down with bronze nuts. They are useful for inspection, but must have small chambers built over this to surface-level, with light galvanised covers.

The usual form of junction with inspection cover is shown in fig. 270. A good pattern interceptor is shown in fig. 271, while a gully is shown in fig. 272. It will be noted that the latter is in more parts than one. This is a decided advantage, as the head can be slewed round to any desired angle before leading in. For the joints of iron pipes molten lead is generally used, but it must be well caulked immediately afterwards. The use of lead wool is equally satisfactory and saves labour. Iron pipes and fittings should be laid in the same way as fireclay ones, with a concrete bed and cradled underneath. A great advantage in cast-iron pipes is that, if desirable, as it often is, in certain situations, they may be suspended on the walls of cellars and basements, gully traps and all, as shown in fig. 273. Before concluding the chapter it may be well to say a few words on earth

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[1] The usual weights per 9-ft. length are:

4 in.			5 in.			6 in.		
cwt.	qr.	lb.	cwt.	qr.	lb.	cwt.	qr.	lb.
1	1	21	1	2	22	2	0	7

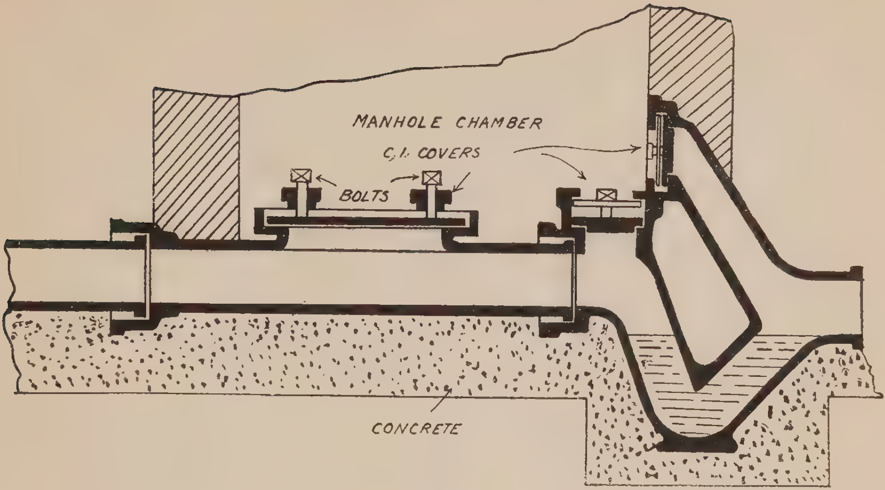

FIG. 271.

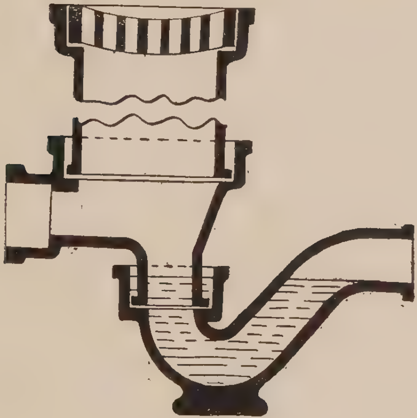

FIG. 272.

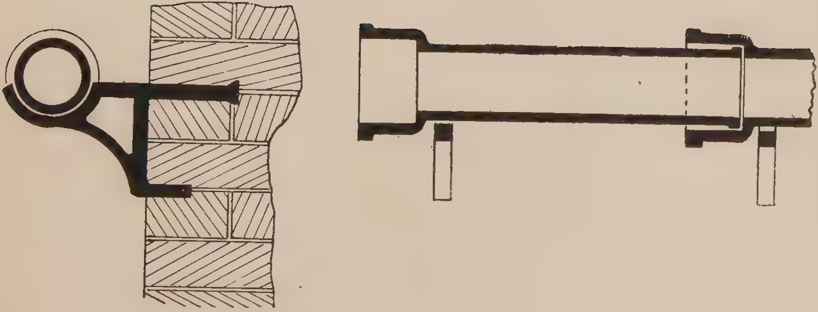

FIG. 273.

closets. It may often happen in the country that, apart from the house system, it may be required to place a single convenience at some distant point, *not* in any dwelling-house, and that to lay a drain to it may be a needless expense. Under such exceptional circumstances an earth closet may prove quite satisfactory; but under no conditions should old-fashioned privies (or petties, as they are called in some districts) be allowed to remain. Moreover, earth closets are not suitable for placing in or near a habitable dwelling, but, when used in the right place, have not the many terrors attributed to them. Dry earth has natural antiseptic qualities, the process being that of oxidation; that is a chemical process, which prevents bacteria acting in a septic or fermentative way. Hence it is that privies and cesspits, being moist, give off such offensive and dangerous effluviæ; but when earth closets are designed so that a plentiful supply of dry earth is delivered automatically after each time it is used, no offensive odour will be perceptible. Moule's pattern is about the most convenient and satisfactory, while mention might be made of a new system called the "Elsan."

CHAPTER X.

SEWAGE DISPOSAL.

When this book was originally written, sewage disposal was just emerging from a more or less chaotic state. This had been brought about by the numerous cranks and faddists, and not a few doctors, who thought they knew something about the subject, all introducing special systems of their own. Many of these were tried out and a few survived.

The Royal Commission on Sewage Disposal then came into being, and, while possibly open to criticism, the body undoubtedly created something like a semblance of order out of chaos. Information on what was thus regarded as quite a complex subject was collected and compared, the operation of various works closely studied, and the matter of sewage disposal eventually appeared as quite a simple problem. As a matter of fact it really is a relatively simple problem, because it is one ordained by Nature in the natural order of things. The offensive odour of excrement is Nature's indication to get rid of it, and decently ordered cities of primitive times made arrangements for carting such refuse out on the land. Here the important process of oxidation took place, rendering the stuff more or less inoffensive. In addition, the nitrogen acted as a fertiliser—another example of Nature's beautiful order of things. Thus under such conditions sewage disposed of itself. Modern civilisation, bringing with it congested town areas, led to the dumping of refuse into ditches and rivers. In place of becoming purified the matter decomposed, with the result that things simply went from bad to worse. Then apparently someone discovered that lime was a good idea, and the matter began to interest chemists. The doctors then came along, and helped the chemists to evolve all sorts of queer processes, which competed with each other for ultimate success.

From an engineering point of view this resolved itself into chemical precipitation, which is still extensively employed. In the meantime, someone else discovered that solids mysteriously disappeared in a cesspool, which was the origin of the septic-tank process of digestion; and chemical precipitation on the one hand, and septic-tank treatment on the other, became recognised methods of dealing with crude sewage. Putting these discoveries on a practical basis involved the labours of many eminent men, and at the end of the last century something like order had been established.

Legislation made it an offence to turn crude sewage adrift, so that tank treatment became general. The effluent, however, was still in a pretty bad state, and the sludge again provided a problem in itself. Under favourable circumstances, turning the effluent and even crude sewage on the land by irrigation systems proved fairly successful, and it thus became generally realised that sewage purification was virtually one of precipitating the solids and oxidising the effluent; and that, in fact, is precisely what sewage purification is.

Land treatment not always being feasible, and even when so possessing many drawbacks, brought about the construction of filter beds. These beds are a great deal more than merely mechanical strainers; they are, as their name implies, bacteria beds, in which the natural process of the land is artificially pastured and incidentally controlled. Hence most works to-day involve—

1. Precipitation tanks (chemical or septic).
2. Bacteria beds (contact or continuous).
2*a*. Land treatment as alternative to (2).
3. Sludge treatment.

Still a further advance has now been made in the activated sludge system. This may be defined as intensive tank treatment, in which part of the sludge is digested in purifying crude sewage, and what is more, purifying to a degree which eliminates the necessity for bacteria beds.

This system, therefore, the value of which has only been proved since the war, greatly simplifies the sewage problem.

Sewage treatment, however, is by no means wholly an engineering problem. It is not a medical one, as that worthy profession would like us to believe, but it certainly calls for the services of the bacteriological chemist, and sewage works management to-day is quite a specialised profession, and upon the observation of works managers improved methods largely depend.

At the time of revising this work for its second edition (1927), the activated sludge process would appear to be on the way to supplant the older systems.

What Sewage is.—While the composition of sewage varies with different localities, mainly on account of the trades' wastes it contains, it is really a definite product. Fresh sewage has a peculiar, nauseating smell, but it is nothing like the offensive product people suppose it to be. It is only when it starts to putrefy that it becomes really offensive, and the whole object of sewage disposal is to prevent this. River channels of thirty or forty years ago were an abomination because of the untreated and putrefying sewage turned into them. To-day the Manchester Ship Canal carries effluent from an enormous industrial area, and is rarely offensive even in the height of summer.

Ordinary sewage is composed principally of animal matters, at least so far as purely domestic sewage is concerned, consisting principally of albumen, gelatine, fibrin, and chondrin, the latter being described in the dictionary as a gelatinous liquid obtained from the tissue of cartilage in the ribs, trachea, nose, etc.; together with vegetable matter, principally consisting of starch and cellulose. It is the former group that give the principal trouble in treatment, which arises from their decomposition or putrefaction by organisms which carry on their operations in the absence of free oxygen, or, in other words, without air. Hence they are termed anaerobic in contradistinction to the aerobic bacteria which thrive in air. Decomposition will also take place, due to the action of aerobic bacteria; but whereas the anaerobic forms generally cause offence, the aerobic do not. In the resulting decomposition CO_2 is freely evolved, at the same time the oxygen combines with the hydrogen to form water. The same reasoning applies to the vegetable matter present in the sewage in a more or less marked degree. Upon examination it will be found that the substances referred to as composing sewage contain oxygen in a greater or less degree, but the purification of effete matters by natural means aims at oxidising all the hydrogen, nitrogen, and carbonaceous matters of which they are composed, the quantity of oxygen already present being inadequate to complete the process. Hence the natural thing to do is to add more oxygen ; this is the aim of all successful forms of purification. It has been realised (without much success) in a process which consisted in blowing oxygen under pressure into the filter beds on to which the sewage is directed. The minute organisms which are always at work attempting to purify organic matter, when they were first discovered, were termed microbes ; with the advance of science they became known as bacteria, and the branch of science which deals with them is known as bacteriology. In a book which aims at dealing with the engineering side of the question, it would be out of place to deal with this science to any extent, however interesting it may be. At the same time a knowledge of bacteriology is very useful to the sanitary engineer, and for the benefit of the reader a few words will be said about bacteria themselves, leaving him to pursue the question further should he so desire.

Mr Dibdin, in his *Sewage Purification*, describes them as follows :—

" These are minute living bodies, some of which are ever present in various forms in or on every substance known, and whenever the circumstances are favourable they bring about the destruction of the organic matters by simply living upon them. In reference to their general character it may be remarked that while at first they were thought to belong to the animal kingdom, it is now generally accepted that they are plants. . . . With reference to the size of the bacteria, it is indeed difficult to describe them in popular language. They vary in length from $\frac{1}{5000}$ to $\frac{1}{25000}$ of an inch . . . a milligram is $\frac{1}{66}$ part of a grain, yet in this small volume no less than 8,000,000,000 of microbes were counted by Bujwid."

Mr Dibdin goes on to say :—

" There are many such organisms doubtless, as we know of their work, but it is fortunately not necessary to enter on a long description of them in order to describe results. It is sufficient to know that they exist, and that we have them at our command to use as we please. They are present in the air and in the waters, however pure, and in enormous numbers in sewage water. All that is required is to give those most suitable for our purpose the opportunity of exerting their beneficial characteristics, when they will infallibly multiply to a degree inconceivable to those who have had no experience of the remarkable manner in which they greedily eat up all that is presented to them under favourable circumstances. . . . What becomes of the dead bacteria is a question often asked. In reply, I would point out that a dead bacterium will only be so much food for his friend, who does not show much feeling in the matter. Such, then, is Nature's method of purification."

The object of sewage disposal, therefore, should be to favour the life of bacteria by providing, as already pointed out, a continuous supply of oxygen or fresh air. To effect this end many expedients have been tried and found wanting, not because they actually failed in providing the oxygen required, but because their *modus operandi* was opposed to natural means. For instance, attempts have been made to dispose of sewage by means of chloride of lime on account of its cheapness, but without success, as it incapacitates the organism, preserves the organic matter for a time, and then partially dissolves it, leaving the foul matter in a worse state than at first. The rapid oxidation of the sewage is prevented by killing the organisms which naturally bring it about. The use of the permanganates of potash and soda has also been advocated, but although they supply oxygen, they are inimical to all bacteria, including those which can destroy the organic refuse by oxidising it much more cheaply, effectively, and rapidly. The same objections apply to carbolic acid, sulphurous acid, and the chemicals generally employed.

The composition of sewage will vary somewhat with different towns according to the water supply, as also in the same town from day to day. In order to ascertain its composition it is necessary to take samples, which must be collected with the utmost care in order to get accurate *average* results. The usual practice is to take hourly samples over a period of twenty-four hours during which normal conditions prevail (viz. no excessive rainfall or drought). They are then mixed, but not in equal quantities from each sample, as this would be faulty, for the reasons given below.

At various times of the day the quantity of sewage coming down will vary—that is to say, one lot will probably be stronger than another. Hence one must mix the samples according to the flow.

The Royal Commission on Sewage Disposal in their first report gave figures which state that an average composition of sewage from a town on the water-carriage system of disposal is as follows, in parts per 100,000 :—

72·2 *solid matter in solution*, containing—

4·696 organic carbon.
2·205 ,, nitrogen.
6·703 ammonia.
10·66 chlorine.

Combined nitrogen 7·728, which is composed of the organic nitrogen and a small quantity of nitrogen in the form of nitrates and nitrites.

44·69 *suspended matter* composed of—

24·18 mineral matter.
20·51 organic ,,

Great variations, however, have been recorded. Mr Corfield, in his *Treatment of Sewage*, 1887, 3rd ed., states : " The total combined nitrogen is found to vary in London alone from about 3 to more than 11 parts per 100,000, while in all the samples examined its variation was from 2·371. Sewage is a complex liquid, most of it, of course, human excrement, urine, stable drainage, slaughter-house refuse, soapy water, and manufacturers' waste. The urine is important . . . because it will rapidly decompose, its natural composition being CH_4N_2O, which breaks up into CO_2 and NH_3 (ammonia), the latter causing both a foul odour and value as manure, the ammonia when oxidised being converted into nitric acid, the chief manurial value of any sewage being the different forms of combined nitrogen, phosphoric acid, and salts of potash, which are usually present in sewage in the undermentioned number of grains per gallon:

“Nitrogen	Phosphoric acid	Potash salts.”
6·7	1·8	1·0

One must always come to the conclusion that the main object in sewage purification is to oxidise the organic matter by the aid of bacterial action, so that such matter will no longer be liable to putrefaction and will be harmless to animal life. The thing is then to see how much oxygen is required to oxidise any particular sewage, and to ascertain the oxygen absorbed, which is taken as a standard of purification.

The organic matter in crude sewage will absorb oxygen in quantities which vary between 3 and 4 grains per gallon, the average being usually put at 3·5, when the sample is a truly average one, collected in the manner pointed out, although the quantity absorbed in some well-known experiments at Sutton was 5·40 grains per gallon, *i.e.* part per 70,000. This applies to crude sewage. The effect of chemicals is to precipitate the heavier solids in suspension and change considerably the matters in solution, according to the strength of the original sewage; the weaker it is, the less marked will be the effect, the degree being ascertained by the amount of oxygen absorbed by those dissolved matters which are unaffected. The above fact is one of the points held to be in favour of the separate system by its advocates.

Chemical Methods.—Sewage naturally contains a large percentage of suspended matter, and it is natural to try and eliminate some of it. This takes place in a small degree, mechanically, in the detritus pits or screening chambers, but in no way renders the remaining liquid immune to subsequent putrefaction; hence resort is made to chemical precipitation. Lime is the principal medium employed, in quantities averaging about 16 grains per gallon, with the result that both suspended and dissolved matters are reduced, and that about 25 per cent. of the organic carbon, as also about 60 per cent. of the organic nitrogen, are removed, but the ammonia will hardly be changed at all; this, if left in, would cause a nuisance, but it can be obviated by treatment to be described later. The addition of chloride of iron appears to be of no advantage. Numerous schemes for precipitation of sewage have been tried. Practically all of them have been found wanting, and it would be useless describing them here. It is well, however, to just enumerate them, so that the reader may not be led astray in the future by one or other of them appearing under a new name.

1. Perchloride of iron, which, although giving both solid and liquid residues, is liable to secondary decomposition by reason of its power of fixing the H_2S and phosphoric acid; it has failed on account of expense.

2. The ABC process, utilising alum, blood, and clay, failed at Leamington, due to smell, and at Leicester, due to imperfect clarification. The principal cause was, however, the failure to produce saleable manure, which was the original intention of the promoters, by reason of the organic nitrogen in the dissolved matters undergoing no alteration; hence the organic matters precipitated from the solution, being devoid of nitrogen, were of no use as manure.

The effluent causes the growth of sewage fungus or *Beggiatoa alba*, an organism which occurs more or less in all effluent water from sewage works.

It appears as dense, flocculent, greyish-white masses attracted to the sides and bottom of the conveying channels. It will appear in effluent waters from chemical works and the deposits of alkali works, and is known to have a power of attracting sulphur from decomposing organic matter. Its presence is therefore generally taken as evidence of a large amount of sulphates, but is not itself considered injurious to water.

Bird's process, which utilised crude sulphate of ammonia, failed to produce a satisfactory effluent.

David Forbes's phosphate process treated the sewage by a solution of the native phosphates of alumina dissolved in sulphuric acid; it gave good results where land irrigation followed chemical treatment, otherwise it has no advantage over the cheaper processes.

Holden's process had the very novel addition of coal dust to sulphate of iron and lime, for what purpose is not stated; suffice to say it was a hopeless failure.

General Scott sought to make cement from sludge precipitated by lime and clay, which it failed to do in sufficient quantity or of a quality to prove of any monetary value. Others, not so well known, are Stothert's process, Whithread's process, Halle's process, MacDougall's, and the N and C process.

Failure of all the above was due, no doubt, to a large extent, to the desire of the promoters to make large fortunes from the manure. It has been proved that such aims are futile, farmers very often requiring payment to take away what was originally intended they should pay for, the actual value of sewage being very different to the theoretical value ascribed to it. In fact, the words of Sir Joseph Bazalgette have much to commend them when he says:

"Sewage must be regarded as an enemy to be got rid of, and not as a friend to be courted and turned to account . . . and to divert the cause of the mischief to a locality where it can do no mischief."

The principal value lies in the ammonia; and taking the average amount of ammonia yielded per head per annum to be 10 lb., the total annual value per head will be about 10s., or for crude sewage about 3d. per ton. Opinions regarding the manurial value of sewage are very conflicting and probably much overestimated; it depends to a certain extent on the precipitant used. The principal crops treated are: Italian ryegrass, hay, mangolds, swedes, turnips, and mint, the last named producing a valuable oil. As stated, the manurial value lies in the ammonia and phosphoric acid, and where these fall short of the required amount it is usual to make certain additions in the shape of sulphate of ammonia, superphosphates, fish meal, etc., the first two being usually employed together, because nitrogen in the form of sulphate of ammonia is of little or no value by itself, especially in the case of turnips and swedes; nor, for that matter, is the phosphoric acid (superphosphate) of much value when used alone. There is, however, in sewage sludge always a certain amount of phosphate, but usually not enough for manurial purposes nor of a proper quality.

In the same way with hay, the nitrogen and phosphates in the sewage are inferior to those contained in manufactured "chemical" manure; they will give fair results on old grass land, but are quite valueless on clay. Lime precipitation alone gives a better sludge from a manurial point of view than when used with iron, because phosphate of lime is very readily assimilated by plants, which is not so much the case with iron phosphate. The same remarks apply to alumina. The value of sludge on land will rapidly fall off when it has to be pressed and carted a distance, because, to be of any practical value, it must provide for at least 40 lb. of nitrogen per acre, and pressed sludge is inferior to crude sludge, as the wetter it is the better. Methods of pressing sludge will be treated later. The cost of pressing is an important aspect of the question ; it depends principally on the amount of lime in the sludge and the quality of the sewage. Sludge in which there is no lime is practically impossible to press ; hence in septic-tank sludge lime must generally be added, which is an expense in itself, and may render it unprofitable to press it. On the other hand, as will be pointed out presently, septic-tank sludge is adaptable for turning on the land in the crude state.

Sludge.—On the whole, then, it may be said that chemically precipitated sludge will lend itself to pressing, and the success of the process depends on the intimate mixture of milk of lime in it. This is because dissolved lime has the effect of binding the solids together. Undissolved lime, on the other hand, will by its presence hasten the removal of the water, because it forms a thin film on the press cloths and prevents their clogging up. The cost of pressing varies from 2s. 6d. to 7s. 6d. per ton under ordinary favourable conditions, which includes the addition of 2–5 per cent. of lime according to circumstances, such as fuel, labour, repairs, cloths, etc., but would not include interest on the plant. The average price *in situ* is rarely more than 1s. per ton. Sludge produced without the aid of chemicals is, however, easier to dispose of, the general practice being to bury it, by digging it in a wet state into the land by means of V-shaped trenches. These are dug about 12 in. deep and 2 ft. wide at surface-level ; that is to say, the top width, when the excavated soil is formed into ridges, is greater than 2 ft. These trenches must be dug some time before sludging, so as to allow of their becoming dry, say six weeks or more, according to the time of year. As soon as they are filled, the ridges are turned over into the furrows, the land allowed to dry, and finally ploughed and sown with seed if required. The drying out, however, is a lengthy process in the winter. The presence of much manufacturers' waste in the sewage is detrimental, inasmuch as the sludge produced is generally offensive, no matter what process is employed. The land required is often considerable where it is not good for the purpose, being usually at the rate of 1 acre of land per 1000 tons of sludge disposed of per annum, and in stiff clay may be as much as 3 acres, sandy soil being the best for the purpose. In most cases lime is added, because septic-tank sludge usually contains sulphides. These sulphides oxidise to H_2SO_4, the neutralisation of which requires lime. In districts liable to heavy frosts the process of disposal of sludge on land is quite unsuitable. In fact there is no system of sludge disposal which is likely to bring any appreciable monetary return, except where grease can be abstracted therefrom.

Land Treatment.—The previous remarks apply to the treatment of precipitated sludge on land ; but crude sewage, after undergoing a preliminary screening, is sometimes treated by the process commonly known as sewage farming. The land may be used to raise crops, or simply for the disposal and purification of the sewage. The system known as "broad irrigation" aims merely at the latter. Although it would be possible to treat small volumes of quite crude sewage in this way in a fairly satisfactory manner, yet it is usual to provide for settling tanks in order to assist in the screening, and to reduce some of the solid and flocculent matter. They are also helpful in storing up the night flow and reducing labour cost. But the land used must be quite suitable for the purpose; that is to say, it should be a light, loose, loamy soil, extending to a depth of at least 5 ft. if no system of underdraining is provided; but when this latter expedient is resorted to, the depth may be less and still give satisfactory results. Clay of any sort is not suitable, stiff clay being quite impervious, while the softer ones crumble down under the action of water. The action of the system is that of allowing the liquid to pass over the land in thin layers. It does not usually sink very deeply, but becomes oxidised by absorbing oxygen from the air. Below the surface, however, a further change takes place, by reason of the ammonia compounds being changed by bacteria into nitrate, which is a chemical change only capable of taking place in the dark. In fact, there is no doubt that with suitable soil of a sufficient area the organic matters in sewage can be thoroughly oxidised by land treatment, and an absorption of 98 per cent. of atmospheric oxygen may be looked for with confidence, provided that the suspended solids are previously got rid of. It is necessary, however, to guard against the land being so light that the sewage passes away too quickly; this is usually done by so laying out the purification beds that the effluent may be inspected and sampled, and if not satisfactory, turned on to other beds at a lower level.

Septic-Tank Treatment.—Septic-tank treatment originated at Exeter in a practical form, and was introduced by Mr Cameron. The works are fully described in most textbooks. Eminently satisfactory results were obtained, as recorded by Mr Dibdin in his *Sewage Disposal* before referred to, in which he states:

"By the biological action in the septic tank itself the organic matter in the sewage was so changed that the amount of oxidisable organic matter in solution was reduced by 30·8 per cent., the free ammonia by 26·9 per cent., the albuminoid ammonia by 17·5 per cent., and the suspended solids by 55 per cent. The condition of the organic matter remaining was also changed, rendering it more easily broken up." This was the result of the first part of the purification. Attached to the works, however, were coke-breeze filter beds, which the writer states had the following results, viz.:—

"The result of the work done by the united processes of septic-tank and coke-breeze filters was an average diminution of dissolved oxidisable organic matter, equal to 80·9 per cent., of free ammonia 54·9 per cent., and of albuminoid ammonia 63·2 per cent., and practically the whole of the suspended matter was removed. Nitrous and nitric acids were also formed, the consistent manner of their production showing the satisfactory conditions of the work obtaining."

The filtered effluent is stated to have been bright and clear, and not liable to secondary decomposition.

The tanks were air-tight and had very little deposit; what there was consisted of—

Moisture .	88·14	per cent.[1]
Mineral matter	7·91	,,
Loss on ignition	3·95	,,
	100	,,

It must always be borne in mind that septic-tank treatment is essentially different from chemical treatment, in that while the latter is a more or less rapid precipitation process, the former attacks the solid by digestion. It is possible, as effected in small installations, to practically eliminate the sludge in this way by long periods of tank treatment, but not only would their capacity have to be considerable, but this procedure affects the quality of the tank effluent, which rapidly deteriorates, due, no doubt, to the evolution of gas in the sludge carrying with it particles of suspended matter, although some consider this an aid to purification. To strike a happy medium, then, *partial* removal of sludge at short intervals gives the best results, because care must be taken that the tank liquor is not so full of suspended matter as to choke the filter. Then, but not till then, the tanks should have immediate attention; if, however, they are completely cleaned, they will take some time to get into a working state again.

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[1] Wood, *Sanitary Engineering*.

The rate of flow through the tank is a very important question, and the medium to be aimed at is maximum settlement and sludge digestion with a minimum of smell. No hard-and-fast rules, however, can be laid down, because of the variety in composition of sewage at different places, which demands equally varying lengths of time for efficient settlement. The form of tank has also an important bearing. A deep tank gives good settlement, especially if circular in plan; a plain rectangular and shallow tank gives a better sludge. In every case slow passage reduces the risk of after smell. The rules laid down in the *Fifth Report of the Royal Commission of Sewage Disposal* state that—

> "From general experience . . . we think it may be safely said that at few places should the sewage remain more than 24 or less than 12 hours in a septic tank, and . . . that the total tank capacity, excluding stand-by tanks for storm water, should be equal to the total daily dry-weather flow."

In the same Report Mr Watson, regarding the septic tanks in Birmingham, states:

> "The actual mean rate of flow through the first set of tanks is 0·87 ft. per minute, and through the second set 0·32 ft. per minute. This rate of flow is sufficient to set up most vigorous fermentation, and results in the destruction of very considerable quantities of organic matter . . . gas . . . and free ammonia."

A very long stay in tanks tends to over-septicise it, and produce H_2S, with its attendant evil smells. It is not now usual to find septic tanks covered in; the process does not require it, because in a "ripe" septic tank a scum rapidly forms on the surface, which prevents light and air penetrating the sewage, and allows the anaerobic bacteria to perform their duties by reducing the nitrogenous matter and organic compounds, which are finally attacked by other bacteria in the scum. In very cold climates, however, a cover may be necessary as a safeguard against frost. In all cases, however, the flow in the tank must be continuous, because, if the bacteria are to break up the organic compounds into inorganic matter, the substances they produce injurious to themselves must be kept below a certain limit. When the tank is first started the bacteria multiply very rapidly; as soon as the useful kind have reached a sufficient number, and until they have acquired their maximum, the tank is said to be ripe; after this, there may be a gradual decline and decrease of activity, owing to an accumulation of their injurious metabolic products.

Chemicals.—The object of all chemical precipitation schemes is to cause rapid deposition of the suspended solids, in order to render the subsequent filtration easy, and to facilitate the oxidation of the organic matters in sewage containing trades' wastes, and it is possible by these means to produce a tank effluent containing not more than an average of five parts of suspended solids in 100,000.

Mr Wood, in his *Sanitary Engineering*, states that about 500 different precipitation processes have been tried from time to time, of which very few have survived to the present day, the two principal in practical use now being lime and alumino-ferric, cheapness being in favour of the former; although Mr Hazen, reporting to the Royal Commission on Sewage Disposal, 5th Report, says:

"The lime process has little to recommend it. Owing to the large amount of limewater required, and the difficulty of accurately adjusting the lime to the sewage, very close supervision would be required to obtain a good result, and even then the result is inferior to that obtained in other ways."

Mr Hazen goes on to say, in the same Report:

"Precipitation by copperas is also somewhat complicated, owing to the necessity of getting the right amount of lime mixed with the sewage before adding the copperas. When this is done, a good result is obtained. The amount of iron left in the effluent is much greater than the ferric sulphate, owing to the great solubility of ferrous hydroxide.

"Ferric sulphate and alum have the advantage over both lime and copperas, that their addition in concentrated solution can be accurately controlled, and the success of the operation does not depend upon the accurate adjustment of lime or any chemical to the sewage. The results with ferric sulphate have been, on the whole, more satisfactory than those with alum. This seems to be due in part to the greater rapidity with which precipitation takes place, and in part to the greater weight of the precipitate. It is probable, from the greater ease with which ferric sulphate is precipitated, that it would give a good result, with a sewage that was not sufficiently alkaline, to precipitate alum at once. It is quite possible that the same process would not give equally good results upon all kinds of sewage. Special sewages may require special treatment. For this reason, and also on account of changes in the prices of the several chemicals, it is impossible to say that one precipitant is universally better than another."

Conclusions.—"Using equal values (*i.e.* as regards price) of the different precipitants, applied under the most favourable conditions for each, upon the same sewage, the best results were obtained with ferric sulphate. Nearly as good results were obtained with copperas and lime used together, while lime and alum each gave somewhat inferior effluents. The range of these results was, however, comparatively narrow; and it may be that with a sewage of a different character, or with variations in the prices of the chemicals, it would be advantageous to use copperas with lime, or even alum. When lime is used, there is always so much lime left in solution that it is doubtful if its use would ever be found satisfactory except in case of acid sewage."

Lime is not easily dissolved in water, and the liquid state (in the true sense of the word) would be an expensive procedure; it is therefore usually added in the form of milk of lime. For use in the solid state "ferrozone" and alumino-ferric are principally used, by placing blocks of these precipitants in the supply channel of the tanks. In selecting any form of chemical or other preliminary treatment of sewage, the predominating factor is how the sludge so produced is to be dealt with, as this is usually the most difficult aspect of the question, while next in importance is the mode of final treatment to be adopted. The latter item demands that the tank liquor shall be in a very good state if the filtering medium is fine; but, provided that the liquor produced is of the required quality, the actual mode of treatment is not so important, except that it has been found that lime causes the liquor to be more or less alkaline, and in the septic process the H_2S is apt to be neutralised to a certain extent; both of which are advantageous in subsequent filtration. The strength of the crude sewage is also important. The sewage from water-closeted towns is generally very strong, and in this case septic-tank liquor would be likely to smell badly, especially if there are breweries in the town which discharge their wastes into the sewers. Another cause of strong sewage is a pumping scheme, which always aims at excluding surface water as much as possible to cut down the expenses, and also allows the sewage to become slightly septic while waiting to be pumped. Hence for very strong sewage chemical precipitation is to be advised.

The proportion of colloidal matter in strong septic-tank liquors is also very considerable, and this clogs the filters, while chemicals successfully throw down much of this colloidal matter and retard the putrefaction of the sludge; in any case lime usually has to be added to septic-tank sludge, which makes pressing difficult, if this is the only method of disposing of it, while chemically precipitated sludges are always cheaper to press than septic-tank sludge, a saving which becomes more manifest the stronger the sewage is. On the other hand, strong sewage may come from a town which has not a large percentage of water-closets; in this case it is mainly due to slop water, and then the suspended matter will settle more easily, and leave only grease to be dealt with. This is usually the case in small country towns. Septic-tank treatment is then advisable, bearing in mind also the variability of the quality of the sewage coming down in such cases. In towns where the strength of the sewage is quite uniform, the choice of treatment is usually a matter of local circumstances, principally depending on the method of final filtration. Septic tanks produce comparatively little sludge, but require a larger area of filter compared with chemical precipitation tanks, which, however, produce more sludge. Finally, in the case of weak sewages, septic tanks are *the* form of preliminary treatment, because the sludge would not tend to swell very much, and the comparative effect of chemicals in weak sewage is decidedly less than with strong sewage, by reason of the fact that it is the last of the suspended matter which is so difficult to throw down. Again, the Royal Commission on Sewage Disposal, in their 5th Report, say, regarding large cities, that—

"The presence of trade waste in large or preponderating quantity has an important bearing upon the preliminary treatment of the sewage from a large city. Where the sewage contained much brewery waste, lime would probably have to be added for the purpose of neutralisation, as at Burton-on-Trent; where it was strongly alkaline or very greasy, acid might have to be used as the precipitant, as at Bradford; where it contained much tarry matter or matter which had an inhibitory effect upon the activity of purifying organisms, septic tanks might be preferable, by reason of the longer stay which they give to the sewage. Manchester may be cited as an example of this last case. For these reasons it is impossible to make any but the broadest generalisations with regard to the preliminary treatment of the sewage from large cities, whether it be weak or strong."

Land Treatment.—The class of soil upon which this process is carried out is very important, because the treatment is a great deal more than mechanical; the soils will oxidise the sewage and absorb organic matters contained in sewage in a very perfect manner. With land treatment the purification of sewage can be brought to a very fine state where the area of the land is ample. By practical irrigation the constituents of sewage are capable of a large amount of reduction, except chlorine, and in a less degree nitrates and nitrites. It is the putrescible organic matter which is effectively purified by this method, which is not always the case with artificial filters. Again, evaporation plays an important part, but is not by any means an essential factor. It is important, however, that the sewage be passed *through* the land, not merely over it, which renders underdraining essential, because, failing this, the effects of evaporation will be such as to cause a concentration of the effluent and retard purification. The plants sown on the irrigation land are of great assistance in purification, provided always that the sewage comes in direct contact with the roots of the plants; especially is this so in the case of certain soils, which by themselves would not form a suitable irrigation area, such as sandy soils, as these would not support crops without the fertilising effects of the sewage water. Suitable apparatus must be provided for distributing the liquid over the ground properly. This will be dealt with in the next chapter, but submersion of the area is to be avoided. Jet distribution is also not advisable in this connection, nor is subsurface irrigation, except in small domestic schemes; open culverts are in all cases best. They are usually formed of concrete or half pipes, and sometimes iron, which is not so advisable as the former; while, if the ground is steep from unavoidable causes, catch-water drains are sometimes resorted to. The ridge and furrow system has given good practical results, but proper underdraining of the area is essential.

One of the principal difficulties to contend with on irrigation areas is the growth of *Beggiatoa alba*. When viewed under the microscope it consists of a quantity of colourless threads, and a number of granular globular particles, which consist of nearly pure sulphur.

Now, regarding the quality of the land on which it is proposed to carry out a system of purification, the soils usually met with are:

(*a*) Sand, (*b*) heavy loam, (*c*) light loam, (*d*) gravelly loam, (*e*) loam and clay, (*f*) peaty soil and sand combined; upon soils such as these one may expect a purification of about 98 per cent., calculated upon the oxygen absorbed. The bacteria will also be reduced to a very great extent. The soils tabulated are all more or less suitable for the purpose, but a peaty soil will not give good results with broad irrigation, while clay is not suited to either system, although it *may* be used in broad irrigation. The efficiency of any system of land treatment is also dependent upon—

1. The quality of the subsoil.
2. The strength of the sewage.
3. The degree of clarification aimed at.

One volume of strong sewage would be easier to purify than two volumes of half the strength on a given area, because of the liability in the latter case of the ground becoming waterlogged. The great advantage of land treatment, however, is that the sludge is easily disposed of. The nitrogen is absorbed by plant life in the form of nitrate, except in very cold weather, colder in most cases than usually prevails in England, especially in view of the fact that the sewage is, comparatively speaking, warm. At the same time the whole of the nitrogen will not be absorbed in any system of land treatment. Chalk land is very unsuitable for land treatment, because, apart from its inability to effect any real purification, there are to be found numerous wells in chalk districts from which water for drinking purposes is drawn, and these wells, unless very deep and well lined down to the impervious strata, are liable to pollution. In this case and in other cases where suitable land is not to be found, some form of artificial filtration has to be resorted to, or what are termed bacteria beds.

Filters: Contact Beds.—Filters are divided into two main classes:

1. Contact beds.
2. Percolating filters.

Their action, like the land, is not mainly mechanical, as the aim is to convert the organic matter into ammonia, marsh gas, and nitrates, in themselves harmless substances. This is effected by bacteria, which must be given every facility to do their work, and hence bacteria beds are not suited to sewage containing chlorine and hypochlorites, nor very acid or very alkaline sewage.

Regarding the two systems enumerated, contact beds are usually tanks filled with some form of filtering material, such as clinker. The bed is filled, allowed to remain full, and emptied after a predetermined period, while the percolating filters allow the liquid to continuously filter through them. Each type of filter has its special merits; each is effective in oxidising the effluent.

Of the contact system, the views of the Royal Commission on Sewage Disposal on this matter are as follows:—

" Single contact beds will, generally, only yield a good effluent where the sewage to be purified is weak, and then only after good preliminary treatment. For the purification of partially settled weak sewage, and for well as also for partially settled sewage of average strength, if the case is one in which a good effluent is required, double contact is necessary unless the preliminary treatment is exceptionally good.

" In nearly every case a greater rate of filtration can be adopted if the material is arranged in the form of a percolating filter than if it is used in contact beds. The rate of filtration per cube yard in the case of percolating filters may, generally, be double or nearly double that which is permissible in the case of contact beds.

" As regards percolating filters, where the liquor to be treated is weak, and the preliminary treatment has effectively removed the greater part of the suspended matter, it is probably best, in most cases, to use fine material arranged in the form of shallow filters.

" Where the sewage to be treated is strong, and especially if the preliminary treatment leaves a considerable quantity of suspended matter in the tank liquor, it is best to use deep filters of coarse material.

" Where the liquor to be treated contains much suspended matter, it is usually advisable to construct percolating filters of coarse material, *whatever the strength of the original sewage.*

"For sewages of about average strength, from which most of the suspended matter has been removed in the preliminary treatment, either coarse or fine material may be used.

"It may be added that, with very well clarified weak sewage, filters with a top layer of very fine material, such as sand, can be made to give good results with a rate of filtration of 400 or even 500 gals. per cube yard per day. In this case, however, the material must be washed (*e.g.* by upward flow of tank liquor) at short intervals of, say, a week."

Much depends also on the size of the medium employed.

With very fine (¼-inch screened) material, the tank liquor should not contain more than five parts of suspended matter in 100,000; if single contact was employed, the rate of filtration could not proceed faster than 200 to 300 gals. per cube yard per day, and 100 to 150 for double contact.

If the material was ½ in. to 1 in. in diameter, a 15-part tank liquor could be treated at the rate of 50 gals. per cube yard for double contact and 160 for single contact; while, again, if the material was as large as 3 in., which is about the limit, a 30-part liquor could be treated at the rate of 30 gals. per cube yard per day for double contact; the actual water capacity of a filter being considered as 33 per cent. of its original capacity as a tank when empty. With percolating filters the results would be more satisfactory; for instance, with a 30-part liquor on a 3-in. percolating filter one could allow a rate of 50 gals. per cube yard per day for ½-in. to 1-in. material, and the results would be about the same as in the case of contact beds, but with ¼-in. material the results would only be about 80 gals. of 5-part liquor per cube yard per day. On no account should strong liquors be passed on to fine filters.

Very fine material, such as sand, is sometimes used for percolating filters when the tank liquor is very weak. They must be scraped and washed by an upward flow in a similar way to waterworks filters. They are usually shallow, and if the liquor is not stronger than 4 parts in 100,000, a rate of filtration of 200 gals. per cube yard may be expected. With contact beds the periods of rest are important, because the bacteria act vigorously on the filtered solids during this period, which also gives ample opportunity to the worms and larvæ, always present in these filters, to do their share of the work. During the actual period of contact the ammonia is extracted from the liquid; it is oxidised by the period of rest into nitrate and nitrite, which finally diffuse into the next filling. In all cases a bed which has been working for some time gives better results in total purification than a quite new one. Contact beds may be filled once, twice, or even three times a day, according to local circumstances. The material of all beds wants periodical washing; the larger sizes want it the most frequently, while the primary beds will only remain in a fit and efficient state about half as long as the secondary ones.

Contact beds are liable to be rendered inefficient from a variety of causes.

In the first place, the filtering material is liable to disintegrate, especially clinker beds. The material appears to wear and to break up. It may be re-used after screening for the secondary beds. In use, also, the beds will get very solid, with consequent reduction of capacity as much as 50 per cent., although the material, except on top, may be quite clean. By turning over the medium, the capacity may be restored to nearly normal. The fine beds clog more readily than the coarse ones. Again, sewage filters, like waterworks filters, owe much of their efficiency to the jelly-like top slime which invariably forms. This, however, may be in such a state as to actually impede the proper action. The slime has the property of absorbing O and giving off CO_2, a chemical change which has been proved of practical value in assisting the aeration of the filter, which is so essential; hence it is that, although the capacity of the filter is impaired, its efficiency increases, but as soon as the decrease in capacity ceases to be of any advantage, the filter must rest for a week or so. In no case must a filter be overworked, because the slime referred to holds liquid, and time must be given for this liquid to overcome capillary attraction and pass off.

Suitably proportioned periods of rest will always cause a gain of capacity in contact beds, due to the biological digestion of suspended matter in the filtering medium, and to the organic matter thereby becoming less spongy and more granular; hence the greater facility for the water to drain away. The gain, however, is only temporary. It is essential to the proper working of contact beds (especially the primary beds) that very little suspended matter is allowed to get on to them. It will also be seen that the loss of capacity of contact beds is rapid at first and then falls off. Suspended matter cannot be entirely eliminated from a tank liquor, and it is for this reason that it is advisable to have a few inches of fine material on the top of all contact beds, which will prevent this suspended matter finding its way into the interior of the bed, and it has been found more economical to remove this layer periodically than washing the beds very frequently. This, however, must in any case be done occasionally, and is usually done mechanically by means of an inclined rotary screen; tank liquor is generally used for the purpose. It costs about 1s. 6d. per cubic yard under ordinary circumstances, which does not include the cost of the plant. Hand washing would cost half as much again at least.

Table XXIII.—Septic-Tank Liquor.

Parts per 100,000.

	Maximum and Minimum Figures.	Average Figures.	Number of Estimations.
Total nitrogen	4·95–8·40	6·75	10
Oxygen absorbed from permanganate at once .	1·17–4·39	3·34	10
Oxygen absorbed from permanganate in 4 hours	5·54–8·64	7·43	10
Suspended solids	5·3 –9·2	6·9	10
Volatile matter in suspended solids . .	4·2 –6·9	5·4	10

The calculated strength of this liquor is 78·7, or, after allowing for the abnormal ratio of the figure for oxygen absorbed at once, to the figure for oxygen absorbed in four hours, 67·6.

Table XXIV. shows the average figures of the analysis of both effluents, with and without suspended matter.

Table XXIV.—Effluents.

Parts per 100,000.

	Analysis of Sample containing Suspended Solids.		Analysis of Sample after Filtration through Paper.	
	Deep Filter Effluent.	Shallow Filter Effluent.	Deep Filter Effluent.	Shallow Filter Effluent.
Number of Samples included in the Average.	10	10	7	7
Ammoniacal nitrogen .	2·92	3·55	2·93	3·54
Albuminoid nitrogen .	0·47	0·47	0·25	0·28
Total organic nitrogen .	0·79	0·84		
Nitrous nitrogen . .	0·13	0·15	0·13	0·15
Nitric nitrogen . . .	1·94	1·35	1·94	1·35
Total nitrogen . . .	5·76	5·64		
Oxygen absorbed at once .	0·86	0·86	0·49	0·58
Oxygen absorbed in 4 hours	3·12	3·09	1·71	2·11
Incubator test (Scudder) .	All passed	8 passed, 2 failed		
Incubator test (by smell) .	All passed	9 passed, 1 failed		
Dissolved oxygen taken up in 48 hours . . .	2·05	1·74	0·65	0·79
Dissolved oxygen taken up in 5 days . . .	6·62	6·49	1·49	1·90
Solids in suspension .	6·40	5·10		
Volatile matter in solids .	4·60	3·80		
Solids by centrifuge (vols.)	73·0	60·2		

Grains per Gallon.

	Crude Screened Sewage.	First Filter 3 ft. 6 in. deep.	Second Filter 2 ft. 6 in. deep.	Third Filter 2 ft. 6 in. deep.
Free ammonia . .	2·36	1·58	1·15	0·83
Albuminoid ammonia .	1·04	0·59	0·43	0·29
Oxygen absorbed from permanganate in 4 hours .	8·90	4·37	2·78	1·93
Nitrogen as nitrates .	..	..	..	0·14
Total solids . . .	123·2	87·6	74·0	7·17
Suspended solids . .	44·2	19·2	7·9	7·7

Another experiment was made by Mr Carter Bell at Salford during the years 1900 and 1901, on the depth of medium-sized material necessary for the purification of Salford precipitation liquor. In this experiment three percolating filters, 8 ft., 5 ft., and 3 ft. deep, all constructed of medium-sized clinker, received precipitation liquor at the same rate *per square yard.* Typical analyses of the effluent are given by Mr Carter Bell in Table XXV.

TABLE XXV.

Grains per Gallon.

	Shallow Filter 3 ft. deep.	Medium Filter 5 ft. deep.	Deep Filter 8 ft. deep.
Free ammonia . . .	2·6	2·4	2·2
Albuminoid ammonia . .	0·20	0·18	0·14
Oxygen absorbed from permanganate in 4 hours .	1·1	0·8	0·5
Nitrogen as nitrates . .	0·84	1·10	1·30
Total solids . . .	65·0	66·0	65·0
Koch's gelatine and incubation test	Fairly satisfactory	Satisfactory	Very satisfactory

Washing has, however, more advantages than a mere increase in capacity. Washed material is always a more efficient medium for filtration than new material, because the process rids it of all loose particles until the material becomes so disintegrated as to render the procedure impracticable.

Percolating Filters.—These are usually deeper than the contact beds; hence, in adopting this system, it is necessary to consider the general levels; but the total depth required *may* be divided amongst two or more filters. The degree of purification from filters of this kind which may be reasonably expected is shown by the analysis given in Table XXIII., which may be taken as average.

The principal reason for percolating filters being deep is that the resulting distribution is more effective, especially where revolving distributors are not employed, as in the case of the Stoddart pattern; an upper layer of fine material is also an advantage in this connection. The general opinion is that per *square* yard the deep filters give better results than the shallow ones, but in the 5th Report on the Royal Commission on Sewage Disposal it is stated that per *cubic* yard, if the filter is given ample opportunity for aeration and good distribution, there is no advantage in a deep filter, except that the oxidation is carried somewhat further. Again, the degree of purification is dependent to a great extent upon the time taken for the liquid to pass through the filter; it is for this reason that clinker is far and away the best material for the bed, because of it being so full of interstices. Coke is also good, however, while broken brick and slag give inferior results. Good aeration is essential to the efficient working of deep percolating filters, hence they must be composed of coarse (not less than 2½-in. gauge) material. When the material is smaller, say ½ in., the advantage is no longer apparent, because the suspended solids will be held for some time in the upper layers of the material, which therefore receive more oxidisable matter in suspension than the rest. Chokage and impediment to equal distribution (another essential to efficiency in deep filters) will then result, and the effluent, being devoid of oxidised nitrogen, will be liable to putrefy. There is also no doubt that much of the air required for aeration is carried down through the top layers by the flow, and that a large exposed side area is not much advantage. Percolating filters of very fine material are not much in use, except in conjunction with Adams (or other) syphons, because of the liability to choke. They are generally closed in at the sides and must be shallow. The effluent produced is not usually very good. They must work at very slow rates. Coarse percolating filters will rarely become clogged if properly constructed, except by fungoid growths or an abnormal amount of fibrous matter in the sewage. They are, however, liable to surface growths, especially in winter and early spring, which will successfully impair the efficiency and cause ponding. With partly settled sewage this is particularly marked, and the distributors get choked in the same way, to avoid which there are special designs described in the following chapter. It has been found an advantage to treat such cases of chokage by growth with an application of a 20 per cent. solution of caustic soda applied to the bed. This will cause a white deposit of sodium carbonate. On restarting the filter the effluent will be very bad, and bring down much brown solid matter, but this will usually disappear within twenty-four hours. Fine percolating filters are not liable to such growths, but the reason is not evident. Chemical precipitation favours these growths.

In order to ascertain the relative efficiency of the various methods employed for final purification, it is necessary to have figures whereby the unit of purification can be expressed. The unit usually adopted is the number of parts of oxygen absorbed in 100,000 parts.

The following table gives an *approximate* idea of the purification which can be effected by different kinds of filter treating different liquors, so as to produce a fair to good effluent :—

TABLE XXVI.

	Units of Purification per cube yard.
Crude or partially settled sewage treated on double contact beds	3000 to 4000
Crude or partially settled sewage treated on percolating filters	2500 to 3500
Well-settled sewage treated on percolating filters .	7000 to 8000 and probably up to 11,000
Septic-tank liquor treated on single contact beds .	3000 to 4500
,, ,, ,, double contact beds	3500 to 4500
,, ,, ,, percolating filters .	7000 to 9000
Precipitation liquor treated on single contact beds	up to 11,000
,, ,, ,, double contact beds	probably up to 6000 to 7000
,, ,, ,, percolating filters—	
(*a*) Filters of coarse material	up to about 8000
(*b*) ,, ,, fine material	up to about 18,000

Disposal of Sewage Sludge.—It has already been pointed out that the disposal of sludge produced by precipitated sewage is often the most difficult part of the process of purification, especially when produced in very large quantities. The main point of difficulty lies in the fact that sludge rarely will contain more than 10 per cent. of solid matter, or about 5 lb. in every cubic foot. The average amount of sludge produced by an average quality of sewage is about 1¼ tons per 1000 people per day, and when chemicals are used for precipitation they will increase this figure by about 40 per cent.

The enormous amount of sludge to be dealt with is thus obvious, and is one of the strong points in favour of septic tanks.

There are various methods of disposal. In small towns it is usually disposed of by ploughing it into the land. It may be run into shallow lagoons and there allowed to dry. It is sometimes made into patent chemical manure, and in very rare cases the grease it contains will repay extraction. The most usual method in inland towns is pressing, and in large seaport towns disposal out to sea in boats. The unfortunate part of any treatment of sludge is that the resulting product has rarely a saleable value large enough to pay for the process. If it has any such value farmers very often refuse it at any price. In view of this it is now recognised that for seaport towns, depositing at sea is the cheapest in the end. The process is at work in Manchester, Salford, London, Glasgow, and Dublin, and other places. In London alone an average of 3 million tons of sludge is thus disposed of annually, but it must be dumped in such places that there is no chance of its being returned to the shore.

Burying sludge in the ground is usually carried on as follows :—

Small V-shaped trenches, about 2 ft. wide at the top and (excluding banking above the surface of the soil) about 1 ft. deep, of sufficient capacity to hold the quantity of wet sludge to be disposed of, are cut, if possible, a month or even two months before they are likely to be required, in order to dry and disintegrate the soil. The wet sludge is then run into the trenches and immediately covered over by shovelling in the earth of the banks. The area thus treated is allowed to remain untouched until it is fairly dry, after which it is ploughed, and either set aside for cropping or used again for more sludge.

It is especially adaptable to sewage farms, but in wet weather the difficulties are enhanced. Smell has also to be contended with, especially in the case of some trade wastes, notably brewery waste, but the addition of lime in this case is an advantage by assisting deodorisation. The amount of land required for the process depends on the quality of the land ; 1000 tons of wet (90 per cent.) sludge can rarely be disposed of per year on less than 1 acre. Sandy soil is the best, clay is the worst ; 3 acres would be a more likely figure in this latter case. The land should be properly trenched previous to sludging, which should always take place in dry seasons where possible. Digging the trenches, which is an important item of cost, may be reduced by forming banks with the excavation, thereby cutting down the amount of actual earth removed.

In place of trenching the land, a shallow tank or lagoon may be formed which receives the sludge. It must have a layer of clinker at the bottom and the bed be underdrained ; but evaporation plays a large part in drying it to a state capable of removal by a spade when it is dumped on waste land. The method fails in wet climates. The sludge is spread about 1 ft. deep.

Another method of disposal, somewhat similar, is that of ploughing an area of flat land and running the sludge on it to about 4 in. deep. It is specially suited to septic-tank sludge, which is well " digested " therein. The process is that adopted at Birmingham. Nuisance from smell is, however, always liable. The sludge dries in a few days, curls up and cracks. Pressing sludge is a means of rendering it disposable rather than actually disposing of it. It must be given a further period of settlement after removal from tanks, and have the addition of lime which will reduce the water to about 60 per cent. The sludge is then ready for pressing in special machines, which will be described. The result is a solid cake which may be disposed of in a variety of ways. Some farmers will pay for it. It is usually inodorous and not liable to putrefy, due to some extent to the lime added for the purpose of facilitating the precipitation. About 1 per cent. of lime is usually added, although as much as 10 per cent. may be necessary, because, while the cake will cost more to press, the lime increases its saleable value. Buyers, however, are not always forthcoming, and it has then to be burnt, for which a specially hard cake is essential. The effect of the dissolved lime is to bind the solid particles together, while the undissolved lime provides minute passages for the escape of water in pressing, especially when lime is applied to the press cloths before pressing. Sludge cake is usually burnt in destructors with ordinary house refuse. It must, however, always be stored in a very dry place, because if once wetted it causes bad smells. It is always more economical to burn sludge when it cannot be sold on the spot. The average composition of sludge cake is as follows :—

Table XXVII.

	Chorley Pressed Cake after drying at 110° C. Sample drawn in April 1905.	Dorking Pressed Cake after drying at 110° C. Sample drawn in April 1905.
Grit, etc. (*i.e.* matter insoluble in hydrochloric acid after ignition) .	25·30	6·84
Oxides of iron and alumina . .	9·37	3·46
Lime	10·32	2·316
Phosphoric acid (P_2O_5) . . .	0·98	0·66
Equivalent to tribasic phosphate of lime	2·14	1·44
Nitrogen (total)	1·28	0·89
Nitrogen evolved on boiling the sludge for two hours with dilute (0·5 per cent.) potash solution . . .	0·13 (May 21st)	0·03 (May 20th)

The extraction of various substances from sludge having a commercial value is not usually a profitable procedure, but in the case of sewage having much grease it may be, because grease has a saleable value of about £10 per ton if of use to soapmakers. The grease is usually the result of a trade waste known as wool-scouring liquor, very prevalent in Bradford sewage. At the same time the manufacturers usually consider it worth their while to extract the grease before it gets into the sewers at all.

The process of recovering the grease consists of adding about 0·0001 per cent. of H_2SO_4 to screened sewage, which "cracks" the grease and causes it to rise to the surface, the acid sewage being finally passed on to settling tanks and discharged ; while the sludge is removed into cast-iron vats, heated by steam to boiling-point and more H_2SO_4 added. It is then pressed while hot, the fat extracted, and boiled and treated by the methods usual with fat boilers.

Sludge distillation is also in vogue. It consists in pressing the sludge and drying the pressed cake. This is then placed in a special cast-iron retort, the volatile products of distillation passing through condensers and scrubbers, which extract moisture, oil, tar and ammonia, and inflammable gas, which helps to keep up the heat of the retort to 1800° F., steam meanwhile being introduced at the bottom thereof. The result is that the steam causes an evolution of nitrogen in the form of ammonia by reacting on the carbonaceous material which is condensed, treated with H_2SO_4, and becomes sulphate of ammonia, the oil being separated from the liquor. There is a residue which might make cement, or, if rich in phosphate, be used as manure.

Effluents.—It will now be concluded from what has been said that purifying sewage consists of removing as much solid matter as possible, disposing of this solid matter in the least expensive and offensive way, and the production of a clear inodorous effluent, not liable to subsequent putrefaction. Very often stringent regulations are in vogue regarding the question of allowing the effluent into inland streams and watercourses. For instance, the necessity of such are obvious in cases like Salford and Manchester, which discharge their effluents into the Manchester Ship Canal.

A resident chemist becomes a necessity on large works.

The Report of the Royal Commission on Sewage Disposal says :

> " For the guidance of local authorities we may provisionally state that an effluent would generally be satisfactory if it complied with the following conditions :—
>
> " (1) That it should not contain more than 3 parts per 100,000 of suspended matter ; and
>
> " (2) That, after being filtered through filter paper, it should not absorb more than—
>
> " (*a*) 0·5 part by weight per 100,000 of dissolved or atmospheric oxygen in 24 hours ;
>
> " (*b*) 1·0 part by weight per 100,000 of dissolved or atmospheric oxygen in 48 hours ; or
>
> " (*c*) 1·5 parts by weight per 100,000 of dissolved or atmospheric oxygen in 5 days."

Unfortunately, even with these results, the effluents will promote low forms of vegetable growths in streams in certain cases. It is the nitrates remaining in the effluent that tend to cause the growths, which are usually of a green colour ; these, becoming detached, find their way into backwaters and putrefy. The grey growths (*Leptomitus*), however, are the worst to contend with, and are caused by a badly purified effluent, especially that from storm-water filters, even if the liquid has previously been found to be non-putrescible on incubation. When found, however, to be putrescible, it is likely that the effluent will absorb much dissolved oxygen from water. Another point worthy of attention is the turning of effluents into streams which operate mills lower down. For the purpose of gaining power, a dam is placed across the stream, and it is behind this that accumulations take place. As long as they remain undisturbed little nuisance is likely to arise, but when it is found necessary to flush out by the sluices or to remove them on to the banks then nuisances will occur (downstream in the former case), and disposal on land should be aimed at. If the cost is prohibitive to the millowner in question. the cost (part or whole) should be defrayed by the ratepayers in the district which would otherwise be liable for pollution of the stream.

Reference has been made to storm-water sewage. As already pointed out, there is no necessity of providing for total purification of more sewage than that demanded by the Ministry of Health regulations. Hence special means are adopted to deal with the extra volumes of sewage sent down by storm waters. It is a prevalent idea that, on account of the regulations, the Ministry of Health consider that storm water is much less foul than ordinary sewage, but unfortunately this is not always the case.

It is inadvisable to pass storm waters direct into a stream where it is at all avoidable, because where a heavy storm follows a long period of drought (frequent enough in the summer), the first hour's flow of storm water is likely to be a good deal fouler than any ordinary flow, by flushing the sewers and washing the streets ; and in hilly districts the rate at which the storm water comes down is a very serious matter sometimes.

The reader is also referred to the previous remarks on storm water in Chapter III., and the effect the various classes of subsoil, etc., have on the discharge. Bearing this in mind, it is generally recognised that in large schemes special stand-by tanks for storm water are essential, and special beds for treatment. The capacity of the tanks should be equal to the maximum excess of storm water over the capacity of the ordinary tank within reasonable limits. They should always be empty when not dealing with storm water. Another estimate of capacity is six hours of the ordinary dry-weather flow. Special filters are also in use in some places for dealing with storm water, but, owing to their not being regularly in use, they very often become inefficient. They must be well constructed, and in such case the cost is usually out of proportion to the purification effected. It is, however, better from a sanitary point of view to bring all storm water to the works and treat it, in place of forming numerous storm sewers to carry crude sewage into streams, but such a procedure adds to the cost of any scheme ; at the same time it is quite possible to allow, when designing the storm-water tanks, for working the ordinary tanks up to three times their capacity.

CHAPTER XI.

SEWAGE-DISPOSAL WORKS.

In the previous chapter the subject of sewage disposal was discussed from a more or less theoretical standpoint. The knowledge of the why and wherefore of the process is very essential to the engineer, but the subject is not one into which he usually goes very deeply or specialises in, as this is the business of the chemist and biologist: the engineer's business is to design certain works to carry out the foregoing principles. These will now be discussed, it being hoped that he has benefited by the condensed information contained in the chapter referred to.

The simplest possible case is that of a country house. The disposal of small quantities of sewage from country houses has in the past not been attended with the success it has had on a large scale, the chief reasons being that simple natural principles have not been properly understood, and that engineers have preferred to devote their energies to larger works. At the outset it may be stated that anything of a complicated nature cannot be tolerated in small schemes, owing to labour not being available, and to the trouble and inconvenience caused by failure. In country houses it is usual, where possible, to collect all rain-water in suitable vessels for use in the summer for gardening purposes, etc. This is equally desirable in connection with the drainage, because it is found that where the sewage is strong it is much more amenable to proper treatment in small schemes.

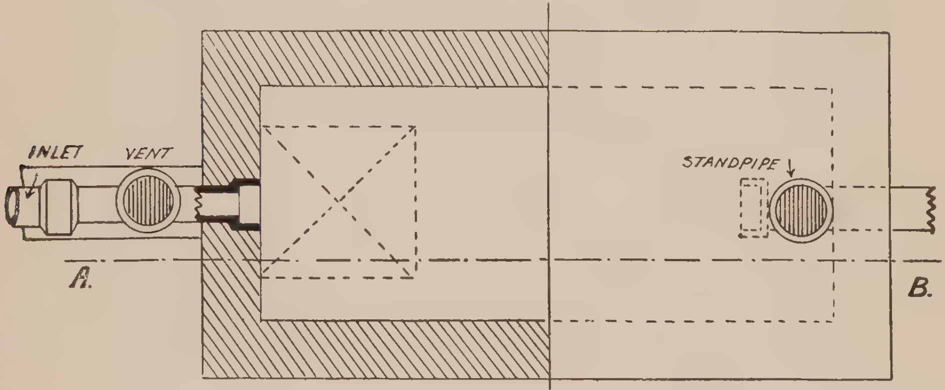


Fig. 274.

Small Works.—The principle adopted in country houses is that of the septic tank for digesting the solids, and some form of filtration for the effluent. In figs. 274, 275, and 276 is illustrated a very simple and efficient type of septic tank suitable for a small country house. The size would

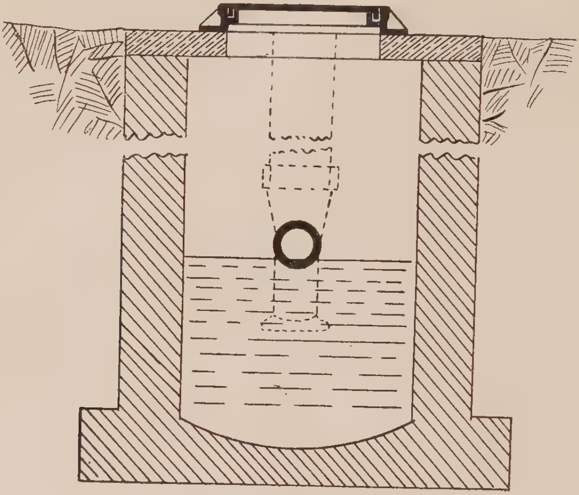


Fig. 275.

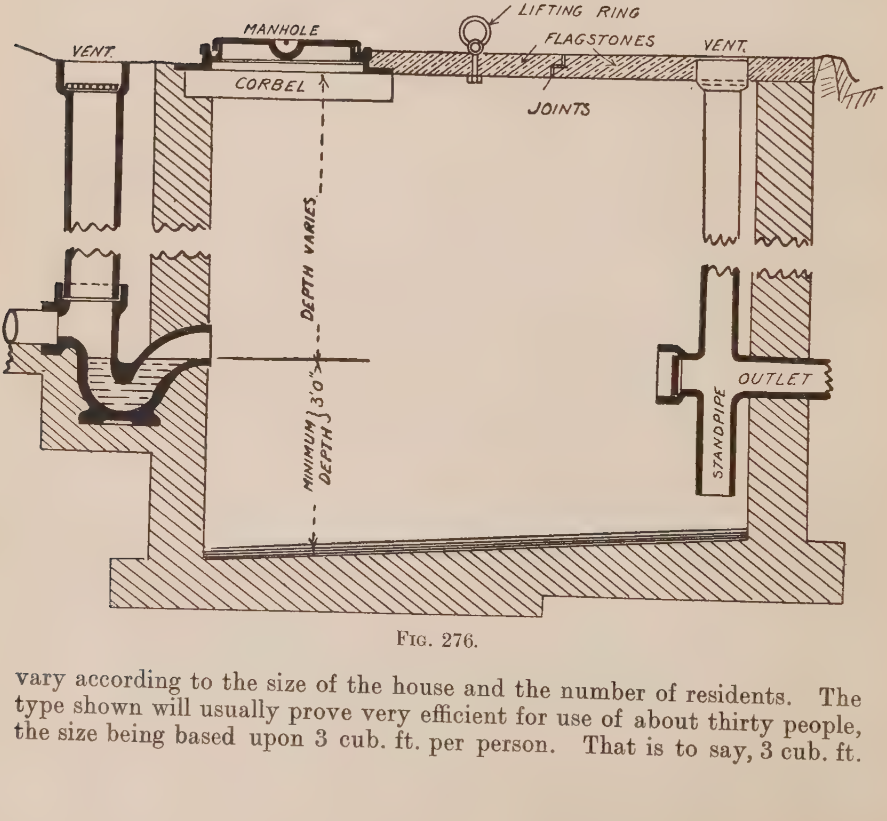


Fig. 276.

vary according to the size of the house and the number of residents. The type shown will usually prove very efficient for use of about thirty people, the size being based upon 3 cub. ft. per person. That is to say, 3 cub. ft.

of liquid capacity, because the depth from roof to top water-level, of course, varies with the depth of the ground. It is not absolutely necessary to carry the whole of the walls to surface-level when the ground is deep. A convenient depth for a man to work in, in case of any repairs being required, is all that is necessary, the earth being filled in over the flags, and a manhole shaft of suitable size being carried up to surface-level, where a cover is placed upon it.

The tank shown would be built of Portland cement concrete of the quality before spoken of, the space between the walls and cutting being carefully filled in with dry stones. The concrete must be quite hard before any water is allowed to touch it. The foundations should have a minimum thickness of 9 in. and be finished with a curved invert as shown. The inside of the tank should be finished to a hard, smooth surface. The covers should be formed of good sound flagstones at least 3 in. thick, and half checkered as shown, the one at the lower end having a hole cut for ventilation to overflow drain. At the upper end granite corbels are built in to support a 24-in. × 24-in. manhole frame and air-tight cover as shown. The design of walls and roofs of large tanks will be gone into presently, but in the case of small ones for house drainage the covering need not be confined to flagstones, although they are usually very convenient to use. The concrete may be laid right across to form a cover ; and as the tank in question is not very wide, will be quite strong enough without any reinforcement, if 9 in. thick and allowed ample time to set before the timber supporting it is removed ; but a few old flange rails will make a sounder job without much expense. Concrete is usually employed for constructing sewage tanks owing to its great adaptability to the purpose.

Concrete: Effects of Sewage.—At the same time attention is drawn to some remarks by Mr Sidney H. Chambers before the Concrete Institute on the subject of the effects of sewage and sewage gases on Portland cement concrete, in the course of which he advanced some views which are liable to disturb prevalent opinion—that sound concrete construction can invariably withstand the action of sewage and emanations therefrom. From Mr Chambers' experience and several years' special study in the matter, it would appear that strong sewage, even of a purely domestic character, may tend to cause disintegration.

The sewage systems upon which his observations were founded were those primarily flowing by gravitation, and secondarily by plenum pneumatic power. The installation consisted of a screening chamber, two detritus tanks, a hydrolytic tank, triple contact beds, and an air purifying filter. The tanks and channels were constructed of Portland cement concrete, the walls of the former being 6 ft. 6 in. at the base and 1 ft. 6 in. at the top, and strengthened by rods. The roof was 6 in. thick, expanded metal being used as reinforcement. The channels were covered by 2 in. indurated paving flags. A few months after the tank was first in operation, the roof and walls above the level of the liquid became discoloured and were found to be covered with a thin layer of sulphur. Subsequently other parts of the tank began to peel, and the concrete had every appearance of deteriorating. A careful examination of the structure was made, and it was discovered that the concrete at the back of the grooves of the main sewage inlet channel, along which the whole of the gases passed to the main air duct leading to the air filter (the withdrawn gases being purified), had disintegrated, although the sides were perfectly sound for a distance. It was found that the greatest disintegration had occurred on the walls at surface water-level. Hence it was concluded that the effects had arisen from the putridity of the sewage and oxidation of the future products of the air supply. The main erosive effect was at the varying liquid level, and was there dependent upon the amount of H_2S in solution in the liquid. When the level of the liquid fell, it left the exposed concrete wetted with H_2S in solution. The surface was then exposed to the action of the air supply, which oxidised the H_2S, and produced sulphur and H_2SO_4, and the concrete thus became decomposed. The rising of the liquid washed away the affected surface, and subsequently a fall would expose a fresh surface to a similar action. The deductions drawn from the investigations were that Portland cement concrete is acted upon detrimentally by gases in solution in sewage where the following conditions prevail, viz. :—

A high degree of putrescence in the sewage, a moistened surface, which holds or absorbs the gases, and the presence of a free air supply. In the absence of any of these conditions little danger from erosion may be feared.

Effluent Drain.—Reverting to the tank, the cascades are to allow of as little disturbance of the liquid as possible, and should reach down to within about 4 in. or so of the bottom. When this is the case and the tank is in good working order, a thick leathery scum will be formed on the top of the liquid, and the tank is then said to be " ripe." Such tanks should not want any attention, and only need cleaning at very rare intervals to remove the sand or other insoluble detritus which settles at the bottom. The effluent should issue in a fairly clean condition ; absolute clarification, of course, cannot be expected. To deal with it, a filter drain is laid down.

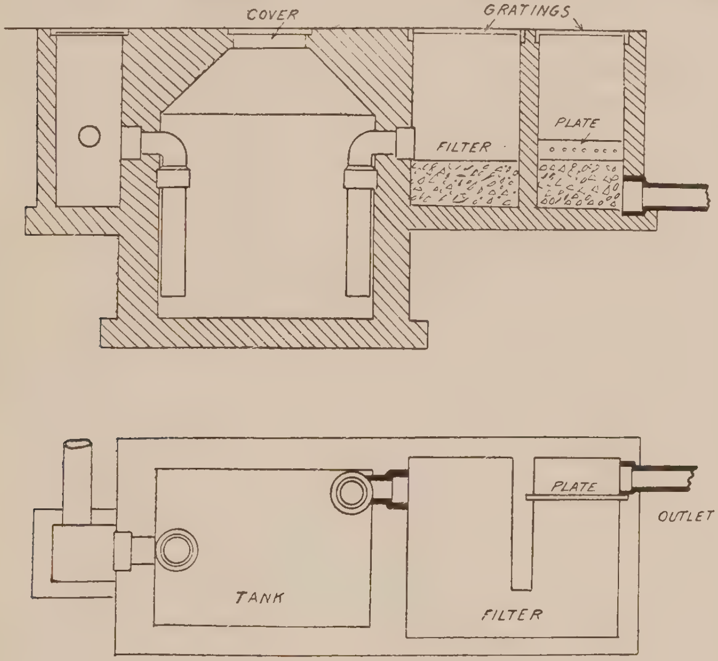
This should be constructed of 6-in. common Scotch fireclay pipe, laid with the sockets downhill and open jointed. It should be laid with a good gradient, the minimum being 1–100 wherever possible, and on a bed 12 in. thick of 3-in. broken stone, and surrounded on each side by 6 in. of similar stone, and covered with 6 in. at least.

It is important to open up the trench to the proper gradients, evenly set out ; the stones and pipes should be carefully placed, and not merely thrown in. A length of about 300 ft. in ordinary absorbent soil will generally be quite sufficient, but should be increased in large installations. If insufficient in length it is an easy matter to extend it, a smaller pipe being used at the lower end. At intervals of 100 ft. dry rubble cesspits should be carefully built about 2 ft. square and with the bottom 12 in. below the invert of the pipe. They should be covered at surface-level with flagstones, having lifting rings. The drain need not be laid more than 3 ft. deep, but should be laid in straight lines between each cesspit, though not necessarily straight from end to end. The end cesspit may, with advantage, be made larger than the others.

In the case of rock and very stiff clay such a form of filter drain as has been described will not be efficient, and will be liable to become waterlogged or choked. It may also be the case that the local authority may demand that some form of artificial filtration plant be installed, although for small installations it is hard to see why any objections should be raised to the subsurface irrigation system. Suffice it to say that, in the writer's experience, local boards' engineers have refused to sanction such schemes going forward. In such cases some form of artificial filter has to be put down.

In very small sizes such filters do not give much satisfaction as a rule, owing to the very small and variable flows; hence where a filter drain can be laid down conveniently their use is not advised.

Plants with Filters.—In figs. 277 and 278 is illustrated another design of small tank for a country house. It will be observed that the sewage first enters a small detritus pit, in order to intercept any large, heavy, solid matter which might find its way through the tank and impair the working of the filter. Attached to the tank is a small filter composed of well-washed coke-breeze about 12 in. and 15 in. deep, held in position by a small perforated plate of iron as shown, which prevents any of the filtering material being washed into the overflow drain. The tank and detritus pit are covered with close galvanised iron covers, while the filter bed should be left open, an iron grating, such as those over areas in footpaths, being useful to prevent people falling into it accidentally. Great care should be exercised regarding the outlet from this and all other filter beds. The nearest watercourse provides the most convenient place, but every precaution should be taken that by doing so no domestic water supply in the vicinity is liable to be polluted. In the same way with the filter drain, every care should be taken to see that there are no shallow wells at a lower level than it in the immediate vicinity. In no case should crude house sewage or septic-tank liquid be turned into a watercourse without some form of filtration, nor should such liquids deliver into an open ditch to soak away. Such ditches more often than not have very little fall and no outlet; the result is that they get very



Figs. 277 and 278.

foul and offensive. It is often found that houses which have quite good drains and septic tanks allow the liquid from the latter to soak away into an old ditch, with the result that very foul emanations arise therefrom.

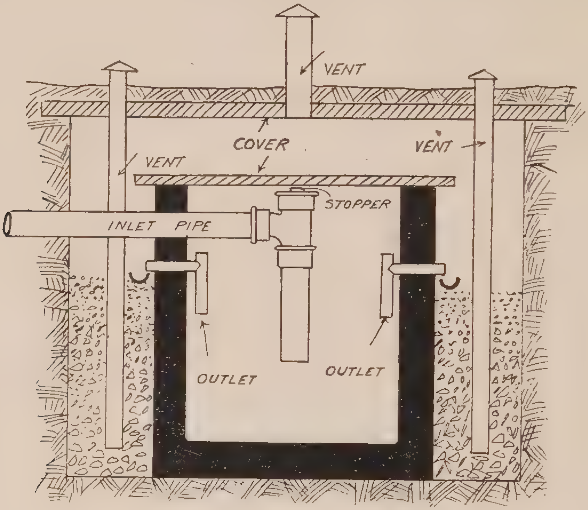


Fig. 279.

The best procedure in such cases is to thoroughly clean out the ditch and remove all contaminated subsoil, lay the filter drain in the clean trench, and

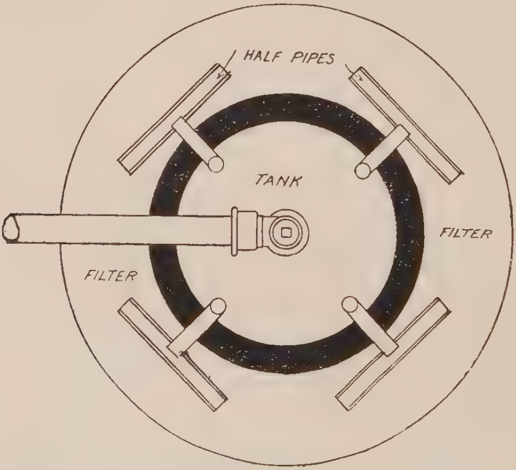


Fig. 280.

then cover it in with fresh dry earth. The system shown in figs. 279 and 280 is rather interesting, as it shows an example of American practice in this direction, the tank being circular, and designed to hold 24 hours' dry-weather flow, the rain-water being excluded. This is a very good basis upon which to calculate the size of a septic tank, because the dry-weather flow from a certain number of people is easily ascertained, and 24 hours is generally considered the most efficient period during which liquid should stay in a small septic tank. It will be seen that there are four outlets, all at the same level, which is 6 in. above the level of the filter bed. Immediately below the outlets half-pipes are placed to assist in the distribution of the effluent and in its aeration. It will be noted that there are cast-iron pipes set vertically in the filter. They are intended to carry fresh air to the lower part of the bed, while an additional pipe is set in the main cover to carry away bad gas from the filter as it rises, the temperature thereof being slightly higher under ordinary conditions than that of the atmosphere. The filter is composed of three layers of different-sized material, the top being very coarse sand (fine sand would rapidly choke up and become useless); the second, gravel; and the lower series, broken stone of the size of walnuts.

In the case of small bungalows, etc., in the country, which are, perhaps, only occupied a few weeks during the year, it may not be desired to go to the expense of putting in concrete tanks, etc.; at the same time provision for one water-closet, or perhaps two water-closets, is desired. For this purpose Messrs Adams & Co. have put forward a rather sound and very simple plant, which is easily erected, and not likely to get out of order. The makers say, in reference to the plant, which is illustrated in fig. 281:

"The above sewage filter has been specially designed for the disposal of the sewage from country houses, shooting-boxes, and isolation hospitals. The sewage from establishments of this kind is, in the majority of cases, principally from the baths, sinks, and carriage washes, and is therefore practically without solid matter. In our system the sewage enters a fireclay liquefaction tank 20 in. in diameter and 12 ft. deep; what solid matter there is remains at the bottom and is periodically removed by apparatus fixed inside, while the liquid passes off to a small filter 4 ft. long by 3 ft. wide by 4 ft. 6 in. deep, over which it is distributed by means of a tipping bucket and distributing tray. It has been found in all cases where the patent system has been installed that there is no smell and a perfect effluent. There is no constructional work, merely the excavation, the brickwork shown being quite optional."

The writer has put down plants of a similar type, only having the fireclay tanks larger. They are really very large sewer pipes of a specially good quality, with iron covers, inlet and outlet, as integral parts of the sections. It is best to ascertain the normal flow of the sewage to be treated, and then send full particulars to the makers, who can best decide as to the most suitable sizes. Two tanks may be used to allow one to work while the other is resting, the distribution being effected by means of a special Y branch, having hand-stop plates in the branches. The filter is of coke-breeze, laid preferably on a concrete base, and held in position by brickwork or rubble walls laid dry. It should be open all round and the excavation well sloped away to allow of ample aeration.

Tank Construction.—Modern practice aims, first of all, at screening the sewage to rid it of heavy solids and foreign bodies. It then passes on to a tank in which it is allowed to stay for a certain length of time, or through which it passes at a predetermined rate. During this process the solids are deposited, or at least a very large percentage of them. When this has taken place the liquid is drawn off and the solid matter disposed of in ways to be pointed out. Finally, the liquid has to undergo some form of purification, in most cases either by means of artificial filtration or land treatment; but in some cases it may pass away untreated if the sewage works are built near to large tidal estuaries. The sludge is disposed of in ways best suited to the locality.

The sides of tanks which are used to store up sewage are, of necessity, retaining-walls, subject to water pressure on one side and usually earth pressure on the other. The subject has already been discussed in a previous chapter, but in the preceding chapter it will have been noticed by the reader that the most suitable depths to which sewage should stand in such tanks are so small that, together with the fact that they are usually subject to earth pressure all round, the ordinary economical thickness of brickwork or concrete, as the case may be, is generally more than sufficient to withstand the thrust of the liquid. A case, however, presents itself in which land for disposal works is limited, and of a sloping nature in parts—that is to say, perhaps, a level tract of land will occur along a river bank which may be very suitable for an irrigation ground, but a rapid rise of ground takes place

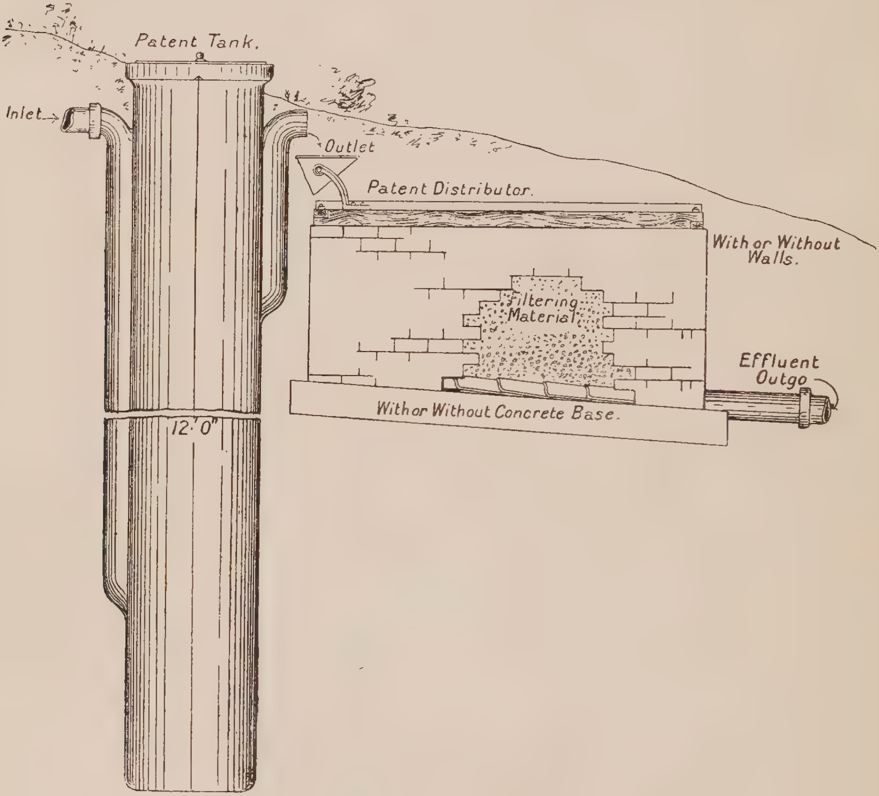


Fig. 281.

at no great distance from the river. The surrounding conditions may demand that the tanks should be placed at the foot of this slope. In this case the masonry work will become more expensive, but may be unavoidable. For instance, referring to fig. 282, the first calculation is that of the earth pressure on the right-hand wall, which in this case is surcharged—that is to say, the earth has a sloping surface upwards from the wall. Set up the line AB at the same angle from the vertical as the natural slope of the earth, and produce the slope of surcharge to meet it in A. Bisect AB and describe the semicircle. Now draw xy perpendicular to AB, cutting the semicircle in y. Now the horizontal thrust at $\frac{1}{3}$ the height of the wall will be equal to

$$P=\tfrac{1}{2}w(AB)^2,$$

=in this case to

$$\tfrac{1}{2}\times\frac{100}{112}(5{\cdot}7)^2=14\tfrac{1}{2}\text{ cwt.}$$

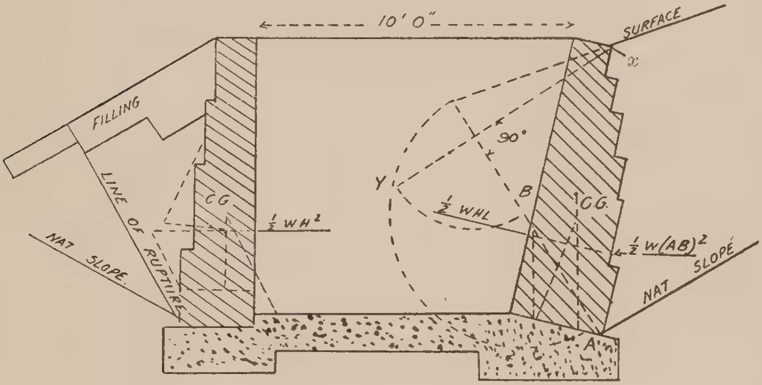


Fig. 282.

If worked out by any ordinary method the weight of the wall will be found to be 25 cwt. In the manner shown this must be combined with the thrust and the resultant drawn. The distance from the point where the resultant cuts the base of the wall from the centre must now be accurately scaled off, the diagram having to be done to a large scale to ensure accuracy. Say it is 0·71 ft., and using the familiar equation

$$\frac{W}{A}\pm\frac{M}{Z},$$

and inserting the correct values

$$\frac{29}{3{\cdot}375}\pm\frac{29\times0{\cdot}71}{\frac{1}{6}\times1\times3{\cdot}375^2},$$

which, when worked out, gives results$=8{\cdot}61\pm10{\cdot}7$, giving compression 0·96 ton and tension 0·1 ton per sq. ft. Now the pressure due to the liquid is

$$\tfrac{1}{2}whl$$

$$=\tfrac{1}{2}\times\frac{62{\cdot}5}{112}\times10\times10{\cdot}3=1{\cdot}43\text{ tons.}$$

Combining this with the previous resultant, a new resultant is found which cuts beyond the inner edge of the base, and consequently

$$\frac{W}{A}\pm\frac{M}{Z}$$

will give the following results:—

$$\frac{32}{3{\cdot}375}\pm\frac{32+2{\cdot}4}{\frac{1}{6}\times1\times3{\cdot}375^2}=9{\cdot}5\pm40{\cdot}5 \text{ cwt.}$$

$=2{\cdot}5$ tons compression and $1{\cdot}55$ tons tension.

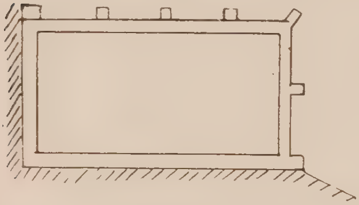


FIG. 283.

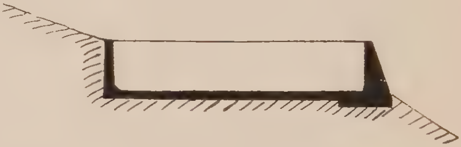


FIG. 284.

In a precisely similar way the left-hand wall may be considered, and it will be found that, as before, the values of compression and tension for earth and water pressure are within safe limits for concrete walls. Tanks of this kind also afford a good opportunity for use of reinforced concrete, because they may not be merely shallow sedimentation tanks, but may be for the purpose of storing flood water or night flow, in which case the depth of liquid will perhaps be greater. In the case of the foundation being porous rock or shale, this method is specially suitable. All organic matter and surface soil should be cut away, the harder bottom exposed and trimmed off level, and the space enclosed by a concrete wall. Assume, for instance, that the ground falls away cornerwise, and that two sides of the tank are exposed as shown in figs. 283–284. The walls lying against the rock would be 6 in. thick at the bottom and 4 in. at the top, and reinforced by expanded metal.

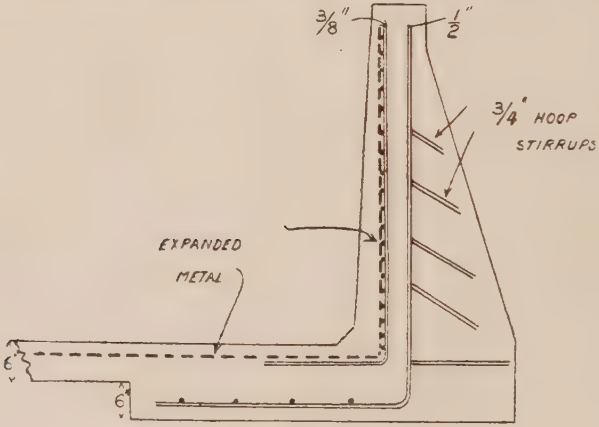


FIG. 285.

It may here be remarked that in a book dealing with sewerage it would be out of place to go into full details regarding the amount of reinforcement required for each particular case. For further information the reader is referred to standard works on the subject and the author's *Civil Engineering Practice*, but in practical work by far the most satisfactory way is to decide upon the form and shape of the tanks, walls, etc., which will be most suitable, and also the particular system of reinforcement to be employed, and then submit the drawings to the manufacturers of the article, who are in the best position to advise the most economical use of their *particular* make.

Returning to the tank, the exposed walls will require buttresses and reinforcement. For the case in question the buttresses would be placed at 7-foot centres and reinforced with $\frac{1}{4}$-in. round rods horizontally as shown, and the vertical ones placed 1 foot centre to centre. The rods are tied together by wire, and expanded metal is shown in its correct position. Regarding the buttresses, the best reinforcement would be two $\frac{1}{2}$-in. round rods and one $\frac{3}{8}$-in. rod, with stirrups of $\frac{3}{4}$-in. hoop iron, as shown. The bottom is reinforced with expanded metal, while the coping would have $\frac{3}{8}$-in. horizontal round bars bound to the vertical ones with wire. The erection of such work, of course, demands the usual skill and attention bestowed on engineering construction work. A detail drawing is given in fig. 285.

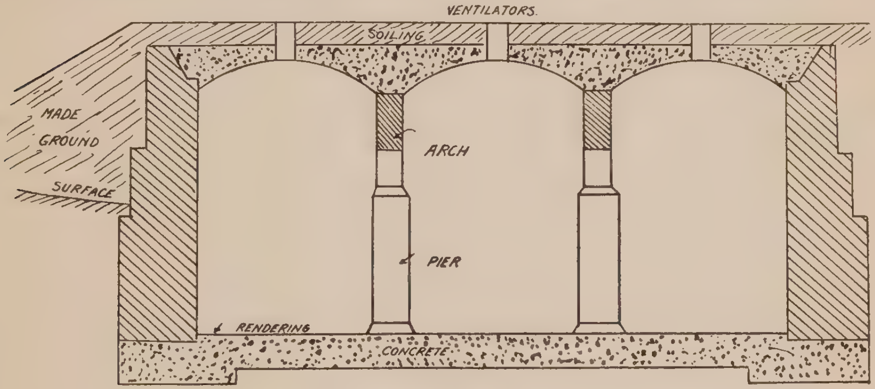


FIG. 286.

It may be necessary to construct closed tanks as well as open ones. For storing up sewage and for septic tanks a roof may often be required, and the most usual methods of effecting this will be described. In figs. 286–287 details are given of a large covered sewage tank. It will be observed that only part of the tank is in cutting, that when built it is covered with earth, and that a bank is constructed all round, but this is not absolutely necessary. In this case it was done merely for the sake of appearance, as it was a stand-by tank for a sea-outfall, placed in a public park. In addition to the side walls, which must withstand the water thrust and the thrust of the arched roof, there are a series of piers, with arches turned between them for supporting the roof. These may be replaced, however, if so desired, by cast-iron pillars supporting rolled steel joists, upon which jack arches are turned, as shown in fig. 288.

Of late years, however, the system of arched roofs has given way a good deal to reinforced concrete, which provides a very satisfactory solution of the problem at considerably less expense, the system being that of beams and floor slabs, as shown in detail in figs. 289–290. No thrust is set up in the side walls. Let the beam be 14 in. deep to the centre of reinforcement by 7 in. wide over all. Its span in this case is shown as 7 ft. 6 in. and its weight will be $\frac{7}{12}\times\frac{14}{12}\times7\cdot5\times\frac{150}{112}$=say 7 cwt., while if the external load is calculated it will be found that about 110 cwt. comes on each beam. On the 7 in. × 14 in. beam over the span in question, the safe load is found as follows :—

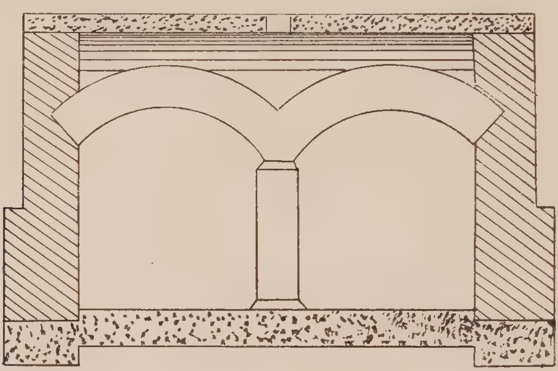


FIG. 287.

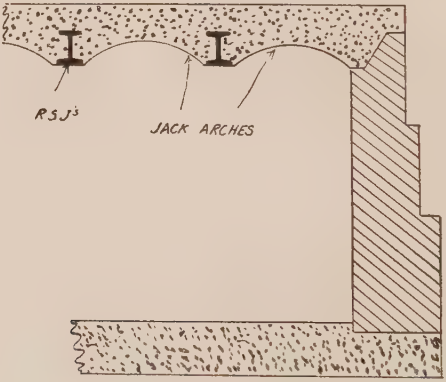


FIG. 287A. (Alternative roof.)

$$W=(0\cdot37p+0\cdot214)\frac{bd^2}{L}$$

$$=0\cdot37\times1\cdot3+0\cdot214\left(\frac{7\times14\times14}{7\cdot5}\right)=128 \text{ cwt.},$$

which is ample, p being the safe stress intensity in lb. per sq. in.=1·3 cwt.

Now in the previous example it was stated, by using reinforced concrete no thrust was set up in the side walls, but in the example in figs. 286–287

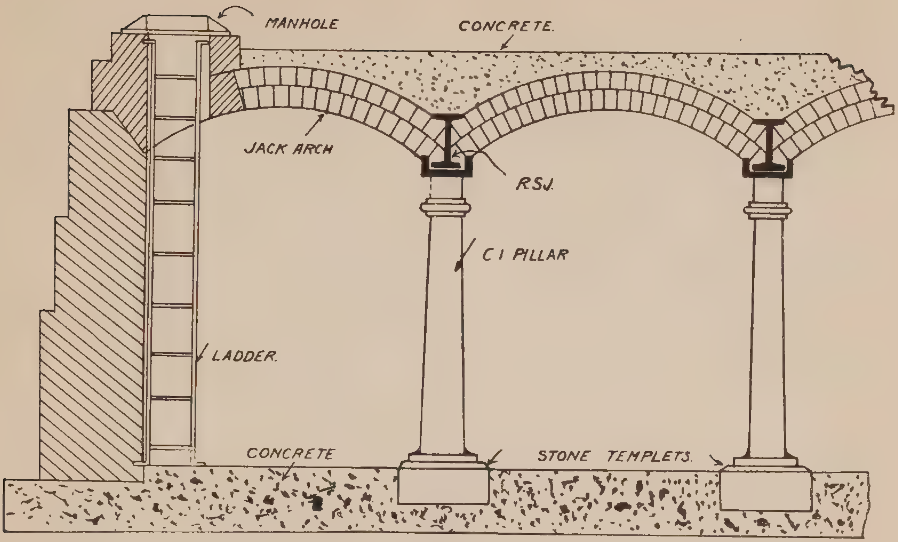


Fig. 288.

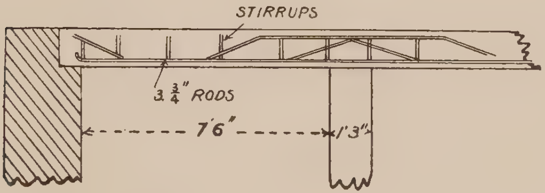


Fig. 289.

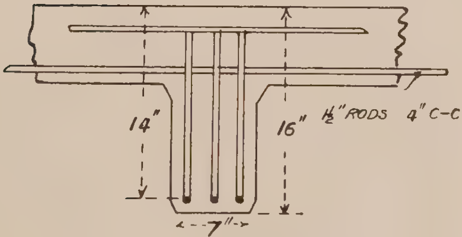


Fig. 290.

there is side thrust, which has to be calculated and provided for, and the method of calculating it is illustrated in fig. 291. Find the centre of gravity of the arch and the load above at A; drop a perpendicular AB, and from the top of the middle third of the crown draw a horizontal line to cut AB in C. Join C to the bottom of the middle third at the abutment. Find the weight of the arch (calculating it at 150 lb. per ft. cube) and the load above (at 112 lb. per ft. cube); set off from C, CB=to that load; and complete the parallelogram DCEB. From the centre of gravity of the wall set up a perpendicular cutting CD in F, and from F set off FG=weight of the wall and FH=thrust at the skew back. Now complete the parallelogram FGJH. Combine this last resultant FJ with the earth thrust, giving

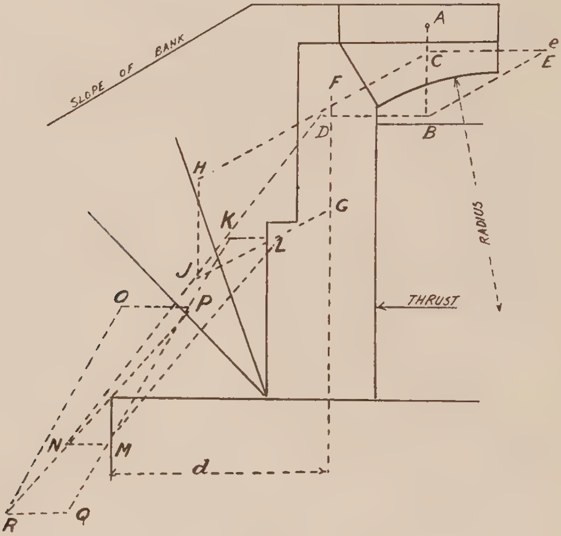


Fig. 291.

the new parallelogram KLMN. Finally, the resultant of the diagram KM must be combined with the water thrust, giving the figure OPQR. If this drawing has been done very accurately and to a large scale, the distance *d* may be measured with accuracy and the intensity of stress found in the usual way by the equation

$$\frac{W}{A} \pm \frac{M}{Z}.$$

Land Filtration.—When sewage disposal first commenced to engage the attention of engineers, treatment on land was considered all that was satisfactory. This has now been proved to be a fallacious idea. Crude sewage is not now often applied to land in schemes of any magnitude. Its use is either for purifying the effluent from septic tanks or chemical precipitation tanks, or for the further clarification of effluent from bacteria beds. Some form of preliminary artificial filtration is very desirable before the liquor from tanks is applied to land, although not absolutely essential. In all cases of land treatment one point must be always before those who have charge of the scheme; that is, efficiency of purification must in all cases have precedence over financial profit. This latter contingency is a very desirable asset, but must be looked upon as a luxury rather than a necessity. Peat and stiff clay are, at the outset, quite unsuitable for the purpose. The best soil is that of a light alluvium nature, such as is found near river banks. It is usually fine in texture, but porous; and, if not allowed to get waterlogged, provides means for rapid oxidation of the liquid applied to it. Some soils get rapidly waterlogged, even if the discharge of liquid into them is by no means excessive, when the subsoil is stiff clay; the most suitable subsoil is either chalk or gravel.

Again, it does not always follow that the land which is capable of the greatest work is the best from a bacteriological point of view, and even the best porous soil will fail if the saturation level is not kept 4 or 5 ft. below the surface. The application of sewage naturally raises the saturation level, and in most cases impedes the work to such a degree that some form of under-drainage has to be applied. This method is superior to ditches for drawing off the liquid, because in the latter case some of the sewage may find its way into the ditches practically untreated. The draining of clay land, although carried out extensively on land-drainage schemes, is not suitable in the present circumstances, as the clay tends to crack, and the liquid passing through the fissures so found is not purified. No hard and fast rules can be laid down regarding the depth and distance apart of the drains; 5 ft. is usually the limit in depth, and 33 ft. the maximum distance apart. Ordinary common field drain-pipes, which are relatively cheap, are used; 2-in. pipes are not of much use, 3-in. pipes are usually laid in branch drains, but it must be borne in mind that the flatter the gradient the larger the pipe should be. For main drains 6-in. common Scotch fireclay socketed pipes are very suitable, laid to even gradients, with sockets turned downhill; all pipes must be laid on, surrounded by, and covered with broken stone or coarse gravel.

There are two principal systems of land treatment:

1. *Broad Irrigation.*—When this system is introduced, the Ministry of Health will require the purchase of one acre of land for every 100 persons supplying the drainage area. The system does not require any tanks; on the other hand, they should be provided to assist in screening, reduction of some of the solid matter, and storing up the night flow. On the whole they are a distinct advantage. It is of the utmost importance that the land selected shall be of a suitable character for the purpose; that is to say, it must be a loose loamy soil about 5 or 6 ft. deep. But even if clay were found to be present below the surface, it might be made very satisfactory by a proper system of subdrainage. Both, however, must be allowed periods of rest. Some clays are sandy and slightly porous; others will consist of a sort of alluvial mud deposit, which will break down when in contact with water. In this system the water does not penetrate very deeply into the ground, but will pass over the soil in thin layers; it takes up oxygen from the air, the ammonia compounds being changed by bacteria into nitrates—a chemical change which, however, will take place in the dark below the surface.

If the soil be not very porous, subdrainage has to be provided. The pipes must be laid in regular lines, at regular gradients, to inspection chambers, where the effluent can be seen, and, if necessary, sampled; then, if the engineer finds it has not yet attained the desired amount of purification, it must be turned into another drain, which by gravitation will bring it on to the surface of a field lower down for more purification. The stipulation of 1 acre per 100 persons is not always adequate. The best results would doubtless be attained by dividing the farm into three areas, the first having a whole year's rest, the second being used intermittently as required, while the third is worked up to its full capacity. Of course this quantity of land, when large towns are considered, is often not readily obtainable. It is the practice to sow such seeds as Italian ryegrass on the farm; or lighter crops, such as wheat and barley, can be produced with advantage. The actual quantity of sewage any particular land will treat, of course, will vary: 200 in. per year is perhaps about the average on each acre. When the land is stiff clay it will crack in hot weather if allowed to get dry; it is therefore essential to discharge on to such land slowly and at a uniform rate, but if this is impossible, a surface coating of clean ashes 15 in. deep will prove effective. If the subdrainage is laid out so that the drains are too close, the sewage will not get enough filtration, and a growth of "sewage fungus" will set up in the pipes. The cells of this "fungus" contain much free sulphur, which it separates from hydrogen sulphide on which it feeds. By oxidising the sulphur into sulphuric acid, the organism obtains the energy necessary to its existence. The land must also have a natural slope; about 1–80 is advisable. The main conduits would be of concrete or brick. They must be of ample size and very flat in the gradient, to get which they are provided usually with overfalls; these also assist somewhat in the purification by aerating the sewage. The outlets would be above the level of the main flow, the sewage being dammed back by weirs. Either of these outlets discharge into what is termed technically a *main grip*. They are trenches about 9 in. wide × 6 in. deep, and at every fifty yards or so have stop plates of wood or iron. A good, inexpensive form of carrier is formed by half-pipes carefully laid and cement-jointed. The following results may be expected on a filtration area of this class properly laid out:—

TABLE XXVIII.

	Solids in Suspension.	Solids in Solution.	Oxygen required to Oxidise.	Free Ammonia.
Crude sewage . .	31·60	47·15	1·99	2·43
Effluent . . .	0·00	30·61	0·534	0·314

The above system is usually employed where crops are grown, and irrigation can only proceed for about four months in the year. This, of course, will necessitate the provision of a good deal of land.

Intermittent Downward Filtration.—Where the soil is very porous this system is often adopted. Loose, sandy soil about 6 ft. deep is essential; when all conditions are favourable, the liquid from 1000 persons may be treated on one acre, and the land may be flooded two or three times a day. It is laid out in plots or terraces set dead level and worked up into ridges and furrows, after the style shown in fig. 292, the ends of each furrow being blocked. Sewage is thus run into each to a depth of about 6 in. and allowed to soak away, the ridges being planted. After each season the ground is ploughed over in such a way that the position of ridge and furrow is reversed. The main carriers are generally cement-jointed pipes, or concrete or brickwork culverts, according to size, and laid on a proper bed to even gradients. The outlet is controlled from chambers having small hand-stop plates set in them for the purpose, as shown in fig. 293. The land must be very carefully laid out and levelled to prevent ponding of the liquid in places; on hillsides it is laid in terraces, which will increase the cost; in very large schemes a set of tram rails is useful for shifting earth during the laying out and levelling.

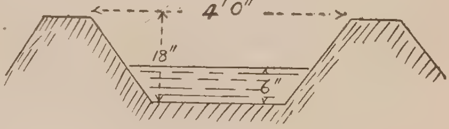


FIG. 292.

It is essential to efficient working that all weeds are kept down in a vigorous manner. They cut out light and air and prevent oxidation. For ploughing, hand labour is, of course, conducive to the best work, but horse labour usually has to be employed on large works. Steam ploughing by endless wire ropes is, however, by far the cheapest, notwithstanding the fact that rough roads must be laid down for the portable ploughing engines to travel upon. On sewage farms such crops as mangolds, cabbage, rhubarb, turnips, and swedes can usually be successfully raised; but the most popular of all is Italian ryegrass, which has a remarkable avidity for moisture.

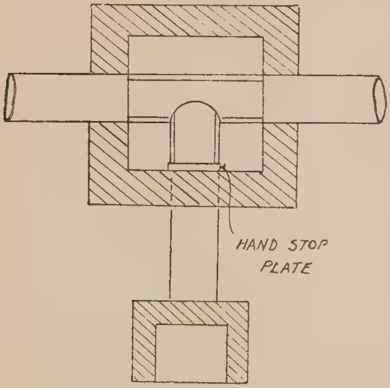


FIG. 293.

Details of an area of land laid out for irrigation purposes is given in fig. 294.

Tanks (Screening).—Before sewage is allowed to pass on to land or artificial filters, or is otherwise disposed of, some form of treatment in tanks is essential, because without it the suspended solids would soon choke the land or filter and render both useless in a short space of time, except in cases where a very large and prohibitive area of land could be devoted to the purpose.

In the first place the sewage must be screened. The screens employed are of various forms, but usually consist of a series of bars, rectangular in section, placed in a frame ½ in. centre to centre. This frame is placed in the inflow channel and usually in such a way that it slopes away from the flow 30° or so. In small works the foreign bodies so intercepted are raked up by one of the attendants and disposed of, but in large works the risk of stoppage must not be incurred through neglect, and automatic rakes have to be employed.

A small electric motor or other form of motive power may be employed to work it; in some cases these rakes are worked by hand.

A typical sewage screening apparatus is shown in fig. 295, and consists of an inclined screen, with taper section steel bars spaced ½ in. apart and upwards at the front edges, supported in cast-iron top and bottom cross-

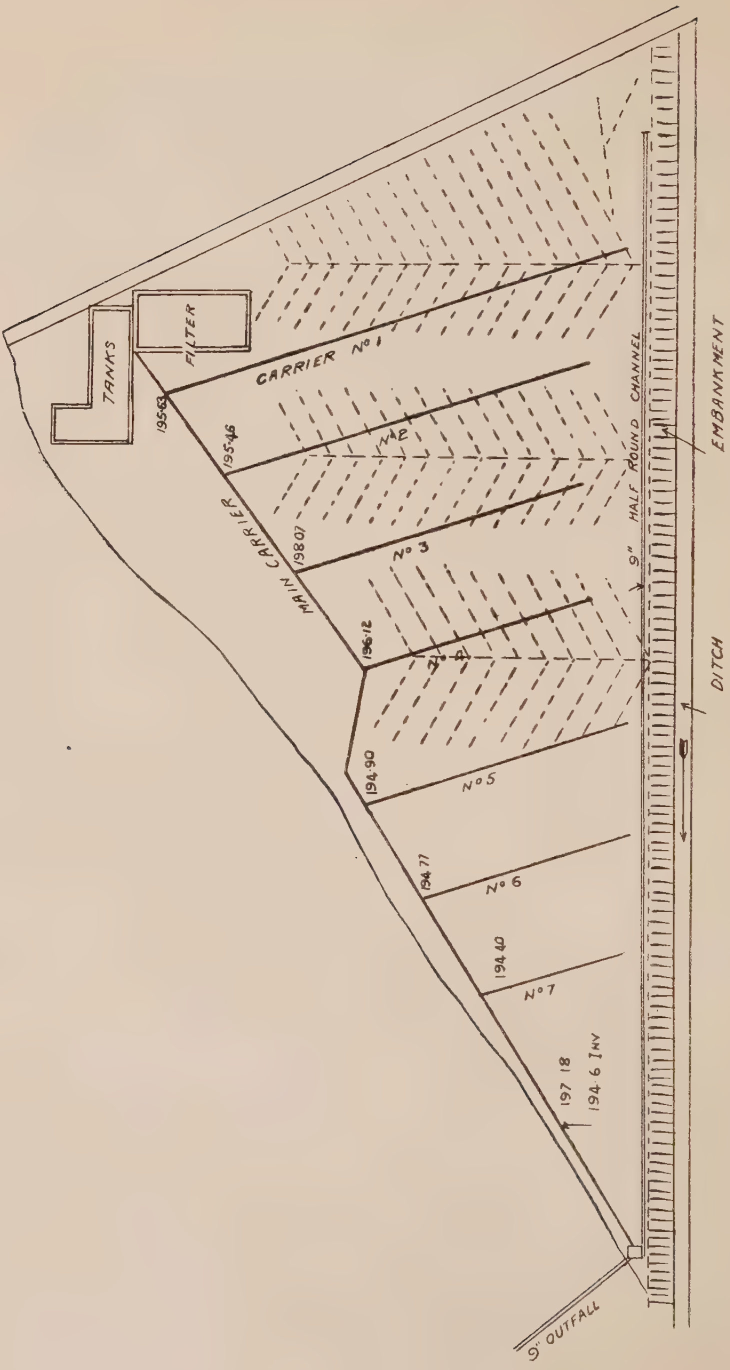

TANKS
FILTER
CARRIER No 1
No 2
No 3
No 4
No 5
No 6
No 7
MAIN CARRIER
195·63
195·46
198·07
196·12
194·90
194·77
194·40
197·18
194·6 INV
9" HALF ROUND CHANNEL
EMBANKMENT
DITCH
9" OUTFALL

Fig. 294.

rails, with channel section side frames, bolted together, and secured to the side walls by means of two cast-iron brackets and rag bolts at the top end, the lower end being embedded in the concrete or brickwork forming the bottom of the sewage channel.

The structure above the coping consists of four angle-iron uprights with flat stays and diagonals, angle-iron guides for the balance weights, and cast-iron tension fixings, with adjustable bearings and tightening screws for the studs which carry the two top sprocket wheels. The two lower sprocket wheels are carried on short shafts with pedestals, and are each connected to a driving shaft by means of spur and pinion gear.

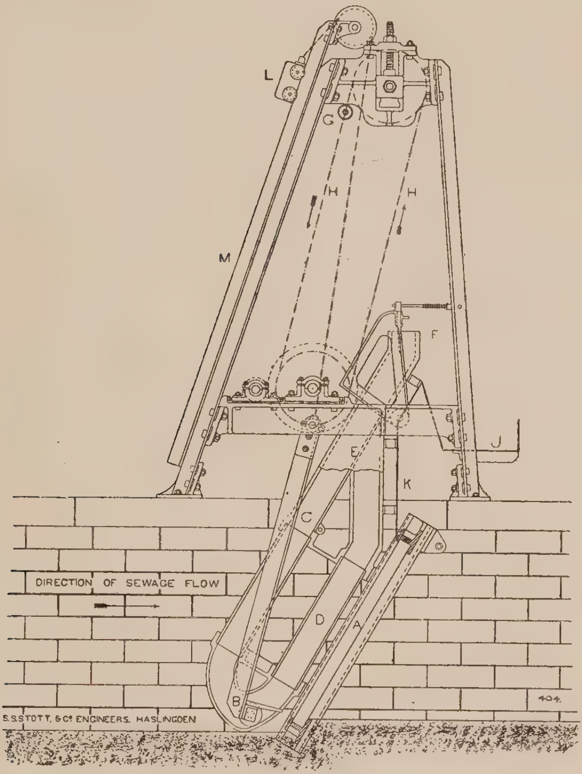


Fig. 295.—Side Elevation.

The apparatus has one travelling cleaning rake, consisting of an angle iron crossbar fitted with a series of prongs accurately pitched to engage in the spaces between the screen bars. The cleaning rake is bolted to the lower end of two vertical angle-iron arms suspended from a cross-shaft secured to a double strand of link chain which travels around the top and bottom sprocket wheels. Runner pulleys are provided at the ends of the travelling cleaning rake for working in the channel section guides, which are secured to the side walls of the sewage channel.

For removing the refuse from the travelling rake an automatic cleaning arrangement is provided on the framework above the coping, consisting of a series of prongs attached to a **T** section crossbar, the latter being secured to a pair of rocking brackets, actuated by the moving chain so as to remove the screenings from the rake and deposit same on the iron table which is provided for this purpose.

The working of the machine is as follows :—

Sewage flowing along the channel in the direction indicated in fig. 295 passes through the screen A, such refuse as is larger than the width of the spaces being left on the front of the taper section bars. The travelling cleaning rake B descends along the front inclined guides C until it reaches the lowest position, as shown, when it commences to ascend the guides D, and at the same time the prongs engage between the screen bars and lift the refuse which has lodged there. When approaching the upper end of guide D the cleaning rake raises two hinged flaps E (one at each side) at the junction of the guides C and D, these flaps being arranged to ensure the rake passing down guide C when commencing to descend again.

When the cleaning rake B reaches its highest position, the prongs, bearing the refuse, engage with those on the automatic cleaner F, and at the same time the rocking brackets carrying the automatic cleaner prongs are tilted forward by means of a projecting roller G on the link chain H, thus delivering the refuse to the table J.

To prevent the refuse falling from the travelling cleaning rake when ascending, a steel plate K is fixed above the inclined screen A.

In order to counterbalance the cleaning rake B a pair of balance weights L are provided, with runner pulleys, working on inclined guides M, and attached by wire ropes to the cross-shaft which carries the cleaning rake.

There is also a type of revolving screen on the market which consists of an endless flexible screen, running round two drums at top and bottom ; as the sewage flows along the foreign borders are deposited on the screen and drawn up, where they fall into a suitable receptacle. A small water-wheel, worked by the sewage, serves to give motion to the apparatus if sufficient fall is available. Messrs Adams & Co. make a screen which is shaped like the letter **L**. There are two screens, and they work up and down in grooves in the sides of the channels by winches and overhead gear. The vertical bars intercept the heavy matter, and the horizontal ones serve to catch it when drawing the screen up, one being in action while the other is being cleaned. The refuse from screens is usually burnt.

Tanks (Septic).—There are two methods of allowing the suspended solids in sewage to settle preliminarily to passing the liquid over land or filters. The aspects of each, from a theoretical point of view, have been discussed in the previous chapter. Modern practice is distinctly in favour of precipitation without chemicals, in what are commonly called *septic tanks*. The action of a septic tank does not merely allow of the suspended solids being deposited, but also partially liquefies them ; consequently they produce much less sludge than tanks in which chemicals are used, always bearing in mind that the actual precipitant goes towards making sludge. The capacity of septic tanks may vary according to circumstances, but the generally accepted rule is, one day's dry-weather flow, this being the time considered most suitable for the passage of sewage through the tank. The shape of a septic tank is quite immaterial ; the rectangular is usually adopted from considerations of cost of construction. The depth may be limited by the surface-levels in view of being able to empty the tanks by gravity, a very desirable state of affairs; but for efficient working the limits are 4 ft. and 8 ft. for the depth of liquid. And it will also be apparent that shallow tanks for a given duty are, of necessity, more costly than deep ones. Again, the square tank for a given capacity contains the least quantity of masonry, but this shape is not recommended. Long narrow tanks are more generally adopted, as, although the sewage must pass completely through the tank during twenty-four hours in order that it will not stagnate but keep up a fairly even movement, which is conducive to keeping up the agitation, the longer the distance it has to travel the greater the velocity, the time interval being the same. Again, the width of the tank decides the width of the weir over which it passes in and out of the tank; and in small installations the film of liquid on the weir may be needlessly thin and dam back the heavier solids. The total tank capacity in small works is usually divided into two units, but in larger ones may be four or more; in any case an even number should be installed to allow of their being worked in pairs. No hard and fast rules can, however, be laid down for tank capacities; sometimes twelve hours' stay in septic tanks is quite enough, because, after travelling long lines of sewers, the sewage will enter the tank partly septic; this will be increased if it has previously waited to be pumped in stand-by tanks. Over-septicising of sewage is detrimental to producing a good effluent, free from smell.

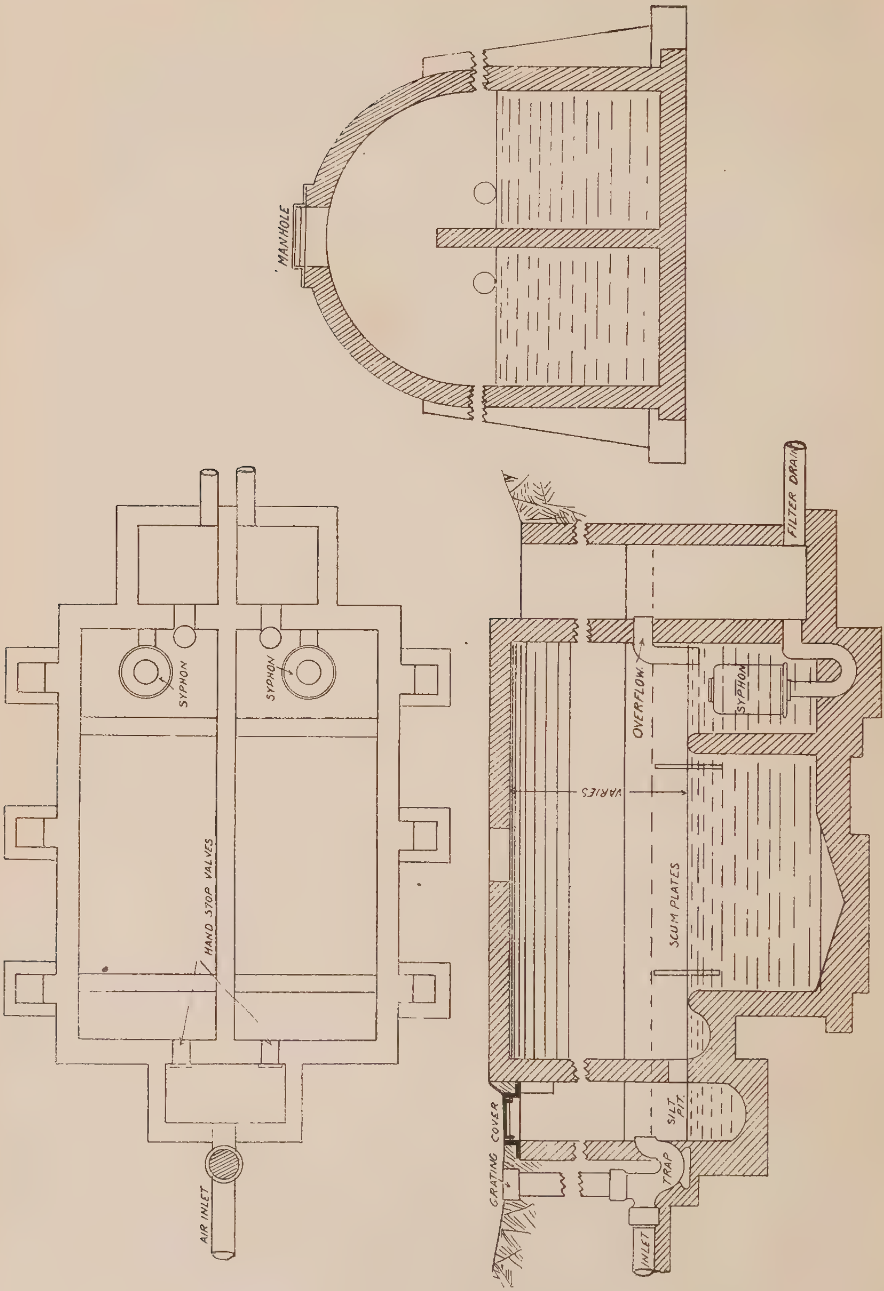
In figs. 296–298 is shown a septic-tank installation suitable for a small works. It is on the simplest possible lines, and the liquid passes in and out over weirs, the scum being allowed to remain intact (which is essential) by means of the scum plates, as shown. These may be formed of wood or iron, or slate if desirable, and placed in vertical iron grooves in the side of the tank. A channel iron or two angles placed back to back and kept apart by distance pieces serves the purpose well. Wooden boards, of course, float, and must be kept at the proper level by stops. In the tanks in question the sewage may be directed to one or the other as desired, while the liquid passes over into another tank in which are placed syphons. Thence it is automatically drawn off in large quantities and discharged into filter drains of the type already discussed. Large tanks must have a slope towards a sludge channel of about 1–50. This sludge channel should be placed at the inlet end, because it is found that at this point the most sludge accumulates. This slope will not allow all of the sludge gravitating away; when the liquid is drawn off, it must be swept down.

The liquid from tanks may be drawn off by what are termed floating arms, the action and construction of which will be understood from the details in fig. 299, but to lower the water to any particular level a series of valves, such as that shown in fig. 300, may be employed. Floating arms are not generally applied to septic tanks. Their action will naturally disturb the scum.

Fig. 300 represents a special adjustable decanting valve or overflow, designed for the withdrawal of supernatant water from septic tanks, etc., at varying levels. It is equally suitable for reservoirs and storage tanks.

A sluice valve may be substituted for the blank flange at base, thus allowing the tank, etc., to be entirely emptied.

It is supplied for any depth of water or size of pipe by the makers.



Figs. 296, 297, and 298.

A relatively new arrangement for decanting liquid from tanks is the decanting shutter. It is shown in fig. 300A. It consists of a series of teak batteries, which are connected together, as shown, by special links, so that they can be lifted successively one after the other for the escape of the liquid. With this apparatus a much larger area for the escape of liquid is obtained than in ordinary decanting systems, thus affording a minimum of disturbance of the settled sewage, and admitting of rapid decanting with a corresponding saving of labour.

Many engineers are of the opinion that scum in a septic tank does not improve the quality of the tank liquor: whether or not this is the case (and the writer is inclined to think that it is so), it does prevent a good deal of smell. It is seldom necessary to completely empty a septic tank for cleaning. The sludge may be drawn off till the issue is seen to be very wet. When it is stopped, of course, the sludge will have to be allowed further time to solidify before anything can be done with it, but this is compensated for by the fact that when once a septic tank has been disturbed, it is some little time before it gets into proper action again. To avoid this and at the same time allow of conveniently drawing off the sludge as required, two methods have been in use for some years. The first is the simple syphonic method of the Dortmund tank. This type of tank is described for its historical interest more than anything else, because, although much employed some years ago, it has now practically gone out of use. It is illustrated in fig. 301. The sewage is seen to enter by a pipe passing through the sides of the tank, turning down the centre and terminating in a bell mouth, 4 ft. from the extremity of the conically shaped bottom. The tank itself is about 20 ft.

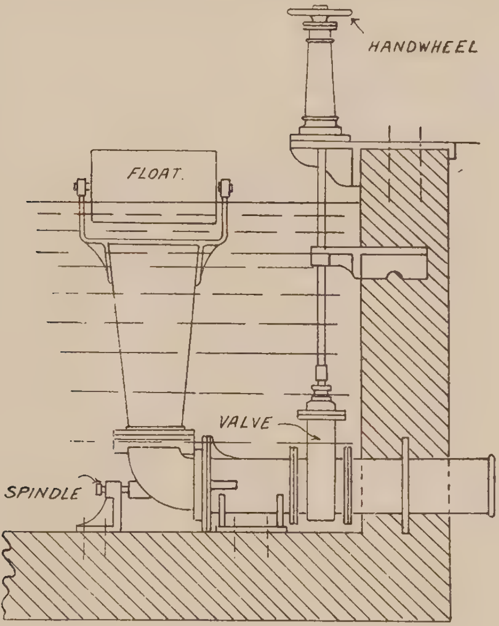


Fig. 299.

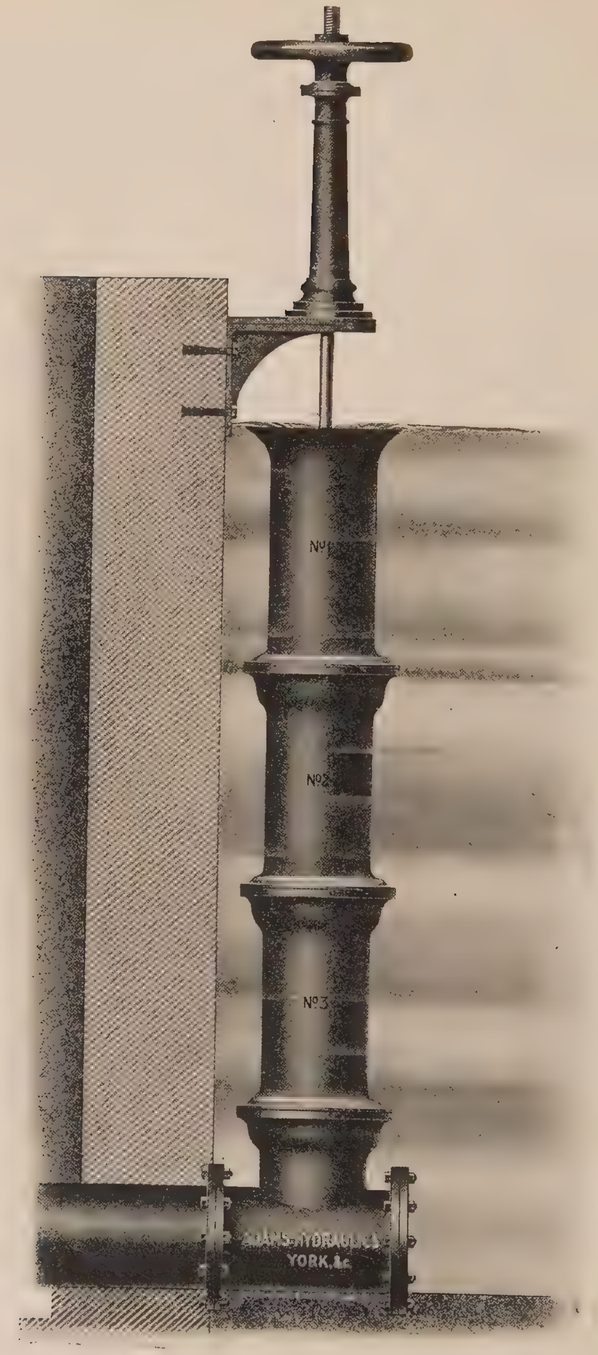


Fig. 300.

deep, and the great advantages it was held to possess lay in the fact that the flow being very slow allowed the solid matter to subside, while the subsidence of particles from the top prevented many of the incoming particles from rising with the sewage. There is a small channel round the side of the tank to carry the effluent away (not shown), while the pressure of the water on the sludge allows of it rising up the pipe as shown. The second method of removing sludge without emptying the tank is illustrated in fig. 302, consisting of a long iron tube parallel with the bottom of the tank and 2 in. above it. It runs on two rails fixed on the bottom of the tank. The pipe is perforated, and attached to it is a rubber squeegee, by means of which the apparatus is drawn along the tank and brings up with it the sludge. At the top of the pipe is a small air pump which exhausts air from it, when syphonic action will cause the sludge to come over into the sludge channel, as shown in the diagram. The same idea is applied to circular tanks; the perforated sludge pipe, instead of travelling along the tank, is made in length equal to the radius of the tank and turns in one direction on the centre of the tank, being connected to the sludge pipe by a special revolving joint. The motion is imparted by a central spindle worked from the top of the tank by ordinary gearing, as shown in figs. 322–333.

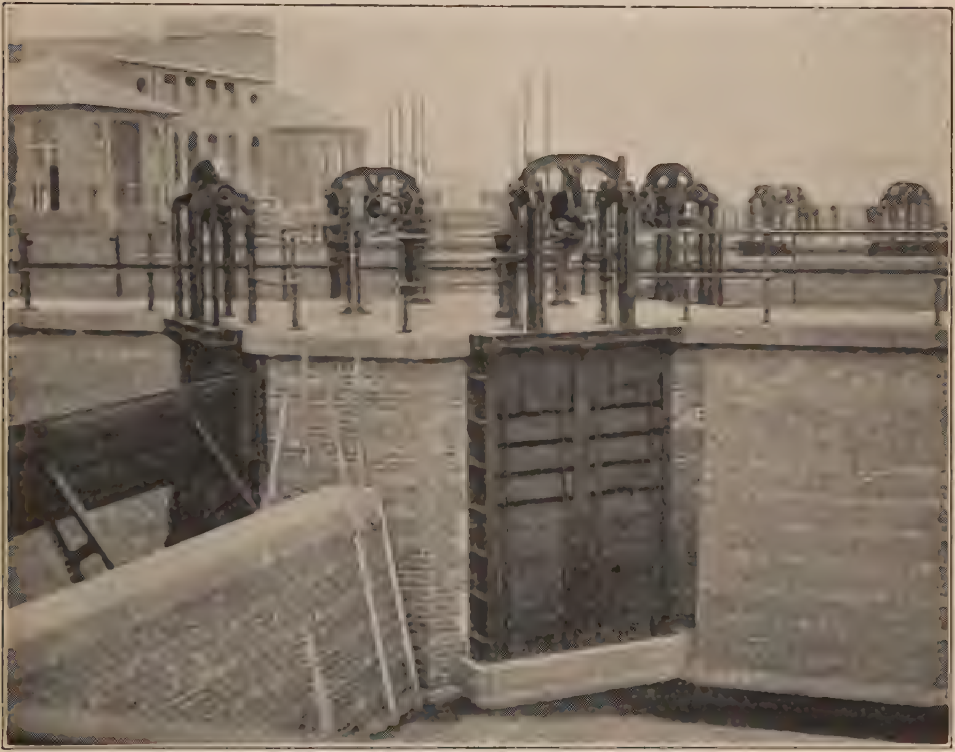


FIG. 300A.

Chemical Precipitation Tanks.—Tanks for chemical precipitation do not materially differ from septic tanks, except that they are not usually covered in. The action of the chemicals consists in becoming entangled with and weighing down the heavier suspended solids, and consequently hastening their deposition. The various systems are discussed in the previous chapter. Lime, alum, and copperas are those which have survived the test of time. The first named is popular, because it is cheap and at the same time rapid. In addition to the tanks for working the system there is a liming plant, which reduces the lime, after it has been slaked to milk of lime, in which form alone it is suitable for the purpose. Liming machines are built by various makers, and in the main consist of a grinder on top to reduce the lime to a very fine powder, on which the success of precipitation depends; below this is the mixer, where the powdered lime is brought in contact with water in the proportion of 1 of lime to 20 of water, the mixture being agitated by paddles to aid the process. Both the grinding apparatus and the paddles are fixed to a vertical shaft, which is rotated by bevel gearing

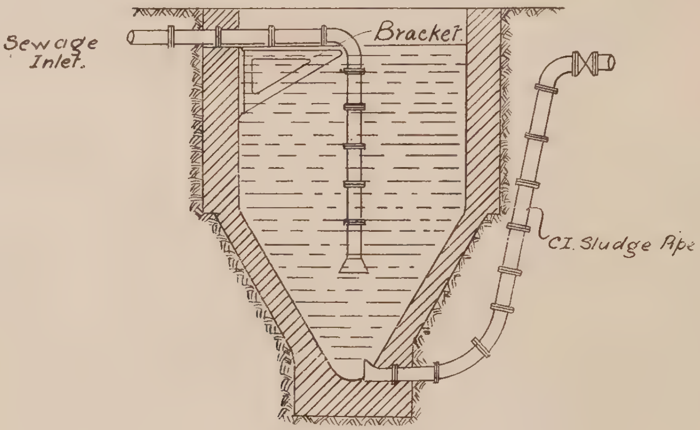


Fig. 301.

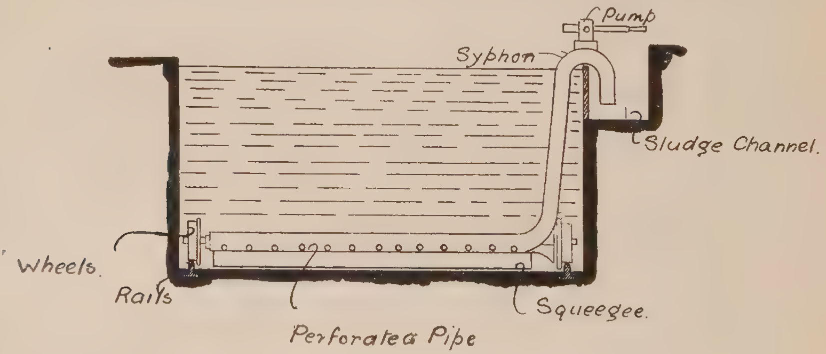


Fig. 302.

driven by means of a belt and fast and loose pulleys, by any suitable form of engine. The necessity for the provision of motive power has caused the lime process to be confined to works of large magnitude, which, by the way, are those usually most suited to this treatment; where the sewage is pumped at or near the disposal works, the lime is generally added immediately after the sewage is raised by passing it along a channel having projecting boards to baffle its flow and induce a tortuous course to aid in the proper incorporation of the chemical.

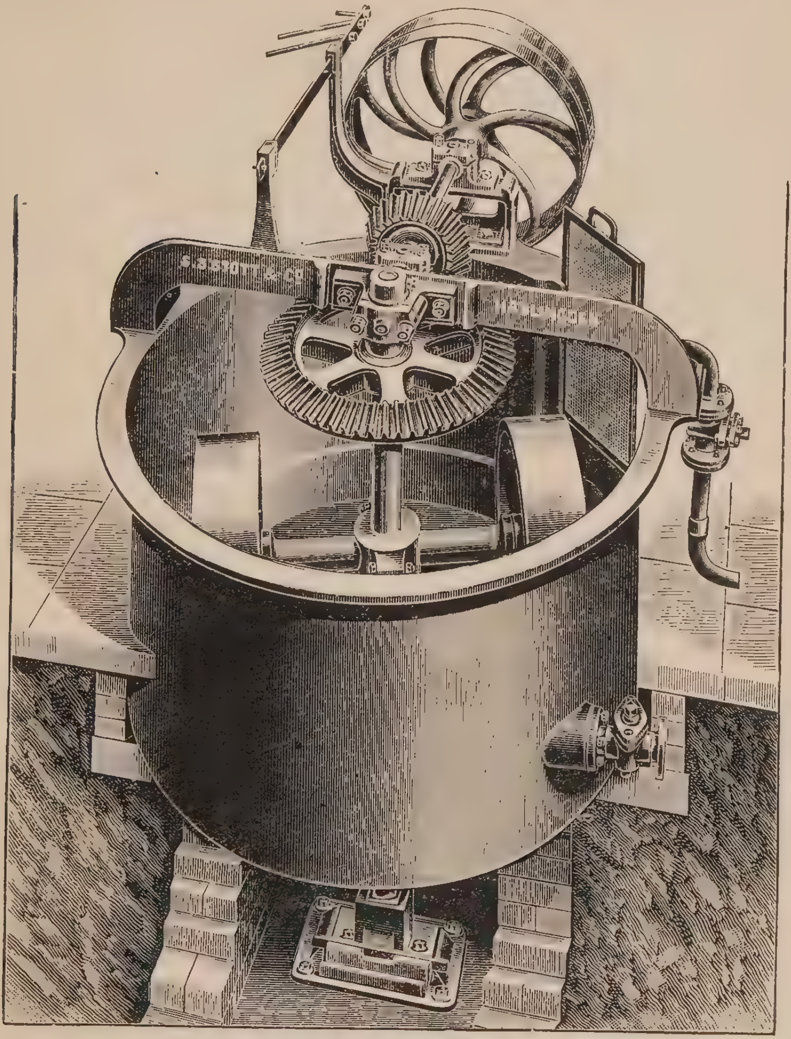


Fig. 303.

A modern form of liming machine is illustrated in fig. 303.

As stated in the previous chapter, lime itself goes to increase the sludge, but this evil is much more apparent when lime of a poor quality, containing up to 30 per cent. of waste, is used. The use of the best lime obtainable is to be advised. Again, all sewage contains CO_2, and the lime will combine with this, the efficiency of this combination being dependent upon the fineness to which the lime is ground before mixing. No hard-and-fast rules can be laid down for the quantity to be used. Each case must be considered on its merits after experiments in use to determine this proportion, but it must be borne in mind that too much lime is not only useless in precipitation, but is so much waste, and it increases the sludge ; besides, when the sewage is overlimed, the acid in the effluent tends to become neutralised, which will result in secondary decomposition setting in. This is a source of great nuisance in river estuaries, and dangerous to fish-life. About 12 grains per gallon is, however, a good average. Copperas, when used, is generally applied in conjunction with lime and afterwards. The proportion of lime is then reduced to $3\frac{1}{2}$ grains per gallon, while $1\frac{1}{2}$ grains of copperas is substituted for the remaining $8\frac{1}{2}$; but the latter chemical is more expensive than lime. At the same time it may be economical to use it when the disposal of sludge presents much difficulty. Copperas, also known as proto-sulphate of iron, is a green salt, and very soluble in water, especially if the water has been previously heated, as is sometimes done by a steam coil. Its use renders the likelihood of secondary decomposition less. In many large towns, where there is already much acid in the sewage, due to trades' wastes from certain manufactures, such as galvanising works, the lime system is alone employed. This usually facilitates matters in the case of lime precipitation, as the acid takes the place of the otherwise desirable, if not essential, copperas.

The only other chemical of any importance is alum, sold in the commercial form of alumino-ferric. It is sold in blocks, which, being placed in a cage, are thus suspended in the sewage as it flows towards the tanks.

Artificial Filtration of Effluent.—Sewage liquor which is treated on bacteria beds must be well settled in tanks and free from matter injurious to micro-organisms. For instance, manufacturers' waste must be examined for antiseptics and germicides, which prevent success in purification of the effluent. The great advantage of bacteria beds over land filtration is that they are much more rapid in action, which is a very important consideration where land is costly or unsuitable. The efficiency or otherwise of a bacteria bed primarily depends upon the class of material used for the filtration, and it should be the best obtainable for the purpose. It is usual to expect a rate of filtration on bacteria beds 100 times greater than that on land laid out as described. This is on an average. Land (which is very desirable for use in conjunction with bacteria beds), however, may be worked up to a very much greater capacity for a short time, as in the case of sudden floods, especially as the sewage from such floods is generally, except in very sudden falls of rain after long-continued drought, somewhat weaker than ordinary sewage. The desirability of land in any scheme of purification is made evident from the Ministry of Health's regulations in reference to storm water, which state that two volumes of storm water *plus* the normal sewage must be treated as sewage proper, while an additional three volumes must receive special treatment, either by a filter used for that purpose only or by passing it over an area of land used exclusively for the treatment of this water ; upon these considerations the works illustrated in fig. 304 were designed. It will be seen that the main sewer enters at A by an open concrete channel and flows to a grit chamber B. Thence it enters a septic tank by submerged inlets CC, of which a longitudinal section is given in fig. 307, and a cross section in fig. 306. The submerged inlets are shown in detail in fig. 305A.

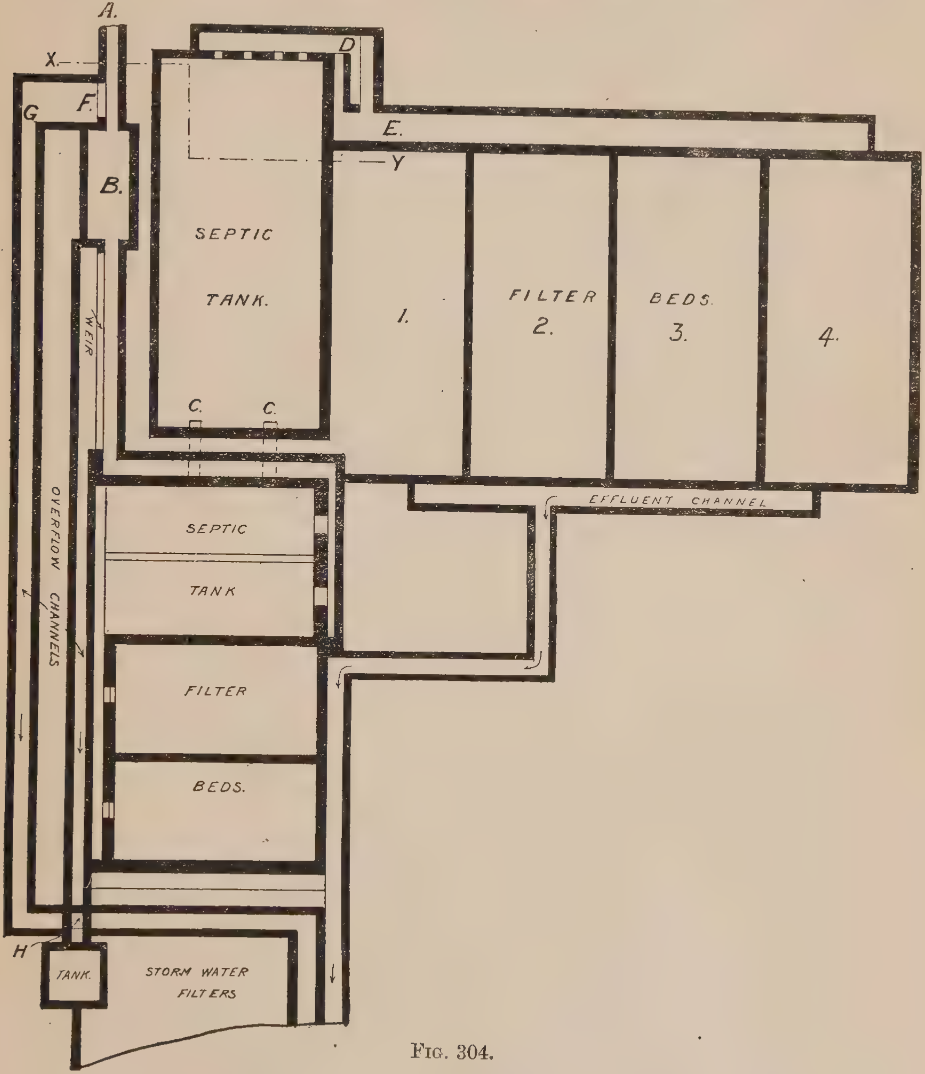


FIG. 304.

The effluent from the tanks enters a channel E after passing through a humus pit D, and passes on to contact beds, as shown. A section of the contact beds is shown in fig. 305. These are operated by Adams' systems, which will be described later on. The effluent passes into the channel as shown, and onwards on to an irrigation ground. Going back to the grit chamber, there is a V notch placed across the channel, which passes six times the dry-weather flow, the excess over that amount passing over the storm overflow weir F into a channel G, whence it flows to a manhole H on to the storm-water filters. The sludge is drawn off from the tanks at a lower level into sludge pits, which are not shown.

Material for Bacteria Beds.—The media for filtering should be as fine as possible, consistent with the proper draining away of the effluent, adequate aeration, and freedom from chokage. Material which is at all liable to disintegration is not at all suitable for the purpose, because the pieces soon settle down in use, and soft friable material breaks up, while the small particles find their way down to the filter drains and choke them; moreover, the bed gets very solid. The considerations in the previous chapter on the point should be borne in mind, the size varying according to the material used and the circumstances there noted. For first contact beds, however, 1 in. is the minimum size; for second contact beds smaller sizes may be used; but extra large material should always be placed round the subdrain to allow of rapid egress of the effluent. There is no doubt that the finer the material the better the effluent, but the liability to failure is much greater.

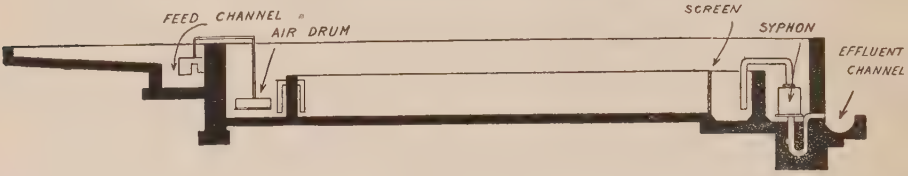


Fig. 305.

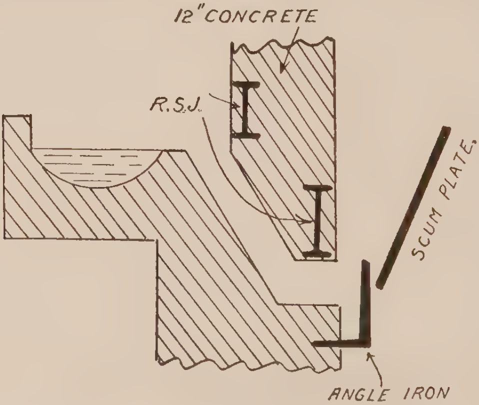


Fig. 305a.

Coke is usually a popular material. It is cheap and generally easily obtained, but is soft and somewhat liable to disintegration. This liability is increased when used for contact beds, because its low specific gravity causes it to float when the liquid rises to the top of the bed; consequently the top layers are moved at every filling. Furnace clinker is, on the whole, the most satisfactory of them all, especially when it is hard and well washed. Its hardness may be measured by its weight; good hard clinker suitable for this purpose should be specified to weigh about 18 cwt. per cubic yard. Clinker from refuse destructors is good.

Slag, obtainable in ironworks districts, is a good material, if it has previously been ascertained by a chemist that it does not contain sulphur or lime. These elements are acted upon by the sewage liquor, which causes disintegration by chemical action. In this case the filter will prove a hopeless failure.

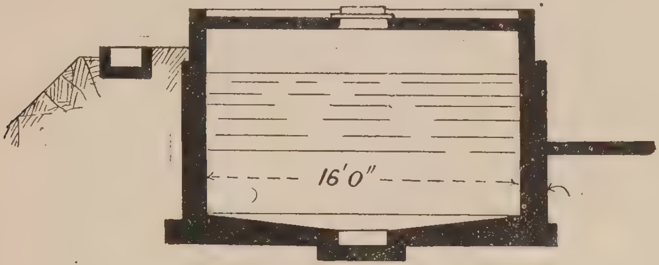


FIG. 306.

Gravel is not as suitable as may be supposed, unless it is very sharp and angular (which is rarely the case), and very well washed before use.

Broken granite, when hard and quite free from dust, is very good for both percolating filters and contact beds.

Broken brick is also very good if the bricks are hard and well washed, especially firebrick. The writer has used, with much success, the broken liners of gas retorts. They are, in his opinion, an excellent all-round material for the purpose.

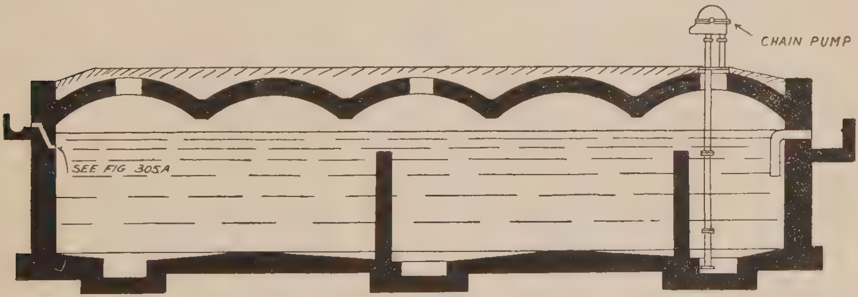


FIG. 307.

Of a similar composition to firebrick are what are known as "saggers." They are peculiar to pottery districts, and are the old broken pots in which fine china has been baked. They are very satisfactory.

Contact Beds.—Contact beds are constructed as tanks of similar form and under similar conditions of stability to sewage liquefaction tanks, the sewage being held in contact with the media for a certain predetermined period. They must be filled and emptied as rapidly as possible, and in small works the capacity of a contact bed is usually a quarter of the minimum dry-weather flow. The reason for so breaking up the total filtering area into small units is that in very dry weather the tanks may take too long to fill up, and large units in contact beds are not advisable. The maximum effective depth is 4 ft.; when new, contact beds have a total water capacity of $\frac{1}{3}$ of the whole, but when they have been in use some time this will be reduced. The media should be renewed every four or five years. Two fillings per day under ordinary circumstances is quite enough. Single contact is unsatisfactory, although land may be employed for the second contact. The second contact beds have finer material than the first, and should be a little deeper. This is not for more effective filtration, but owing to the reduced space between each unit of the bed. When the first contact bed is simultaneously discharged, the liquid will rise over the surface of the second bed if they are both of the same capacity; this superabundance of liquid passes away unpurified; besides, the load of water tends to solidify the bed, decreasing its capacity. The floors of contact beds must slope to one point and be made of concrete; and in the depression, drains are laid. These may be simply round field drains, or one of the two systems shown in figs. 308 and 309 may be employed; or the tank may have a false bottom, formed of tiles of the class shown in fig. 310.

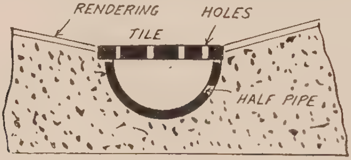


Fig. 308.

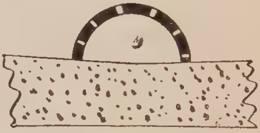


Fig. 309.

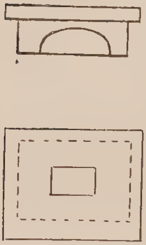


Fig. 310.

The application of tank liquor to bacteria beds of the contact type is usually effected by means of automatic syphons, as described in an earlier chapter, although various mechanical devices have been tried.

A small installation of septic tank with primary and secondary beds, employing syphons for distribution, is shown in figs. 311, 312, 313. The liquid from the septic tank flows over on to the coarse bed. After a period of contact the liquid is automatically syphoned over on to the fine bed. Connected with this is a timed syphon. This differs from the syphon on the primary bed, which is merely enclosed by a perforated iron shield, inasmuch as it is enclosed in a separate chamber; a small cock, which is adjustable, delivers a small portion of the liquid to the syphon, which, when the liquid rises to a predetermined level, automatically draws off the whole contents of the bed. The rate at which the liquid rises in the syphon chamber, and consequently the duration of contact, is controlled by the adjustable cock to give the best results, as found by trial. When there is a series of beds to be filled, as would be the case in a large works, a modification of the above principle is employed.

Fig. 314 shows a large scheme of contact beds on to which the liquid is discharged in rotation by syphons, and automatically discharged therefrom by similar syphons, the arrangement of effluent and feed channels being very compact.

The principle employed is that of air-lock feeds as shown in fig. 314A. A is the sewage supply channel, B the automatic air-lock feed, C an air pipe connected with the dome D. Sewage passes freely from the channel

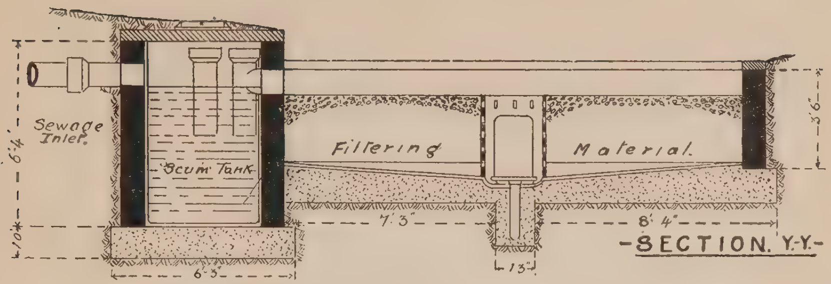


FIG. 311.

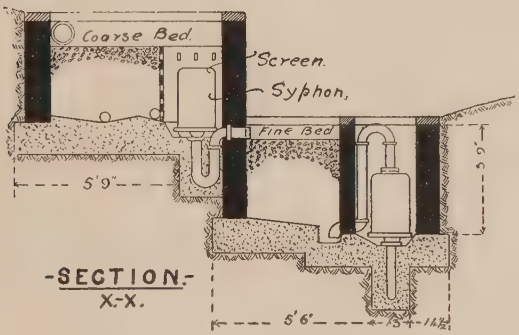


FIG. 312.

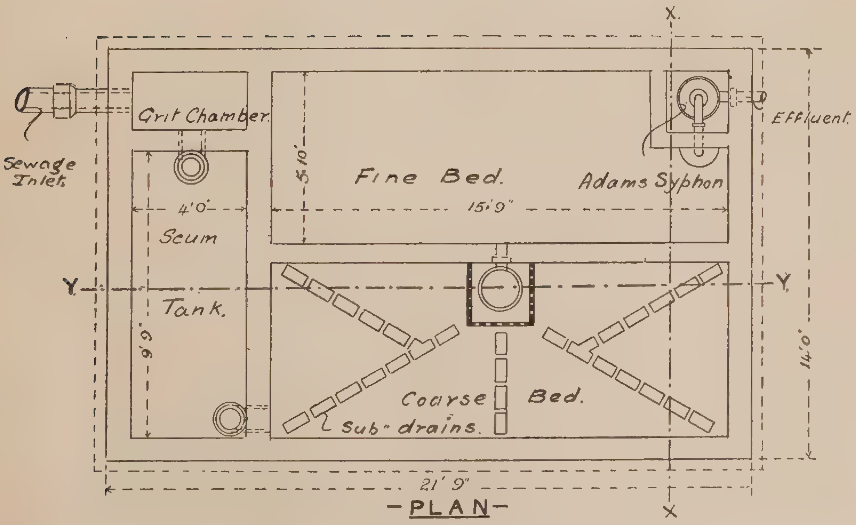
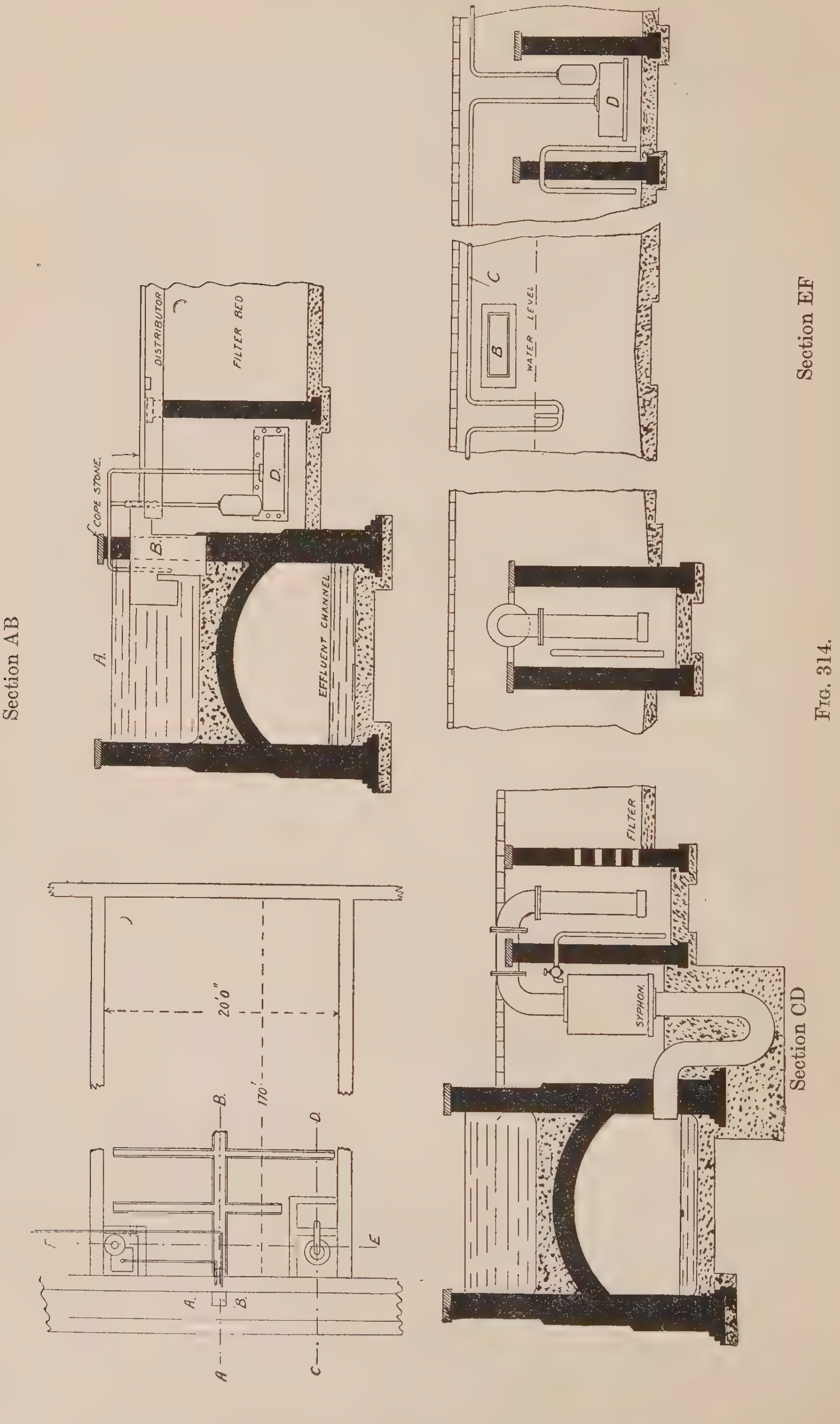


FIG. 313.



Section AB

Section EF

Section CD

Fig. 314.

through the apparatus and is distributed by the trough to the bed. The wall F serves as a screen around the dome D; when no air lock exists, the level rises as the bed fills until the dome D is reached. The air within is put under pressure due to the still rising liquid; when the full height is reached, the air from the dome is transmitted through the pipe C to the interior of feed B, where it creates an air lock, thereby cutting off the further supply of sewage. The bed then rests for saturation. The feed is finally unlocked to the passage of liquid and the air within it is allowed to escape. The escape is brought about by an added volume from a dome placed in any desired bed bursting the seal of the main trap or an auxiliary water seal.

Percolating Filters.—These are bacteria beds in which the sewage is not kept in contact with the medium for a predetermined period, but is continually distributed over the surface by some method or other in the form of a spray, the filtered effluent being simultaneously drawn off.

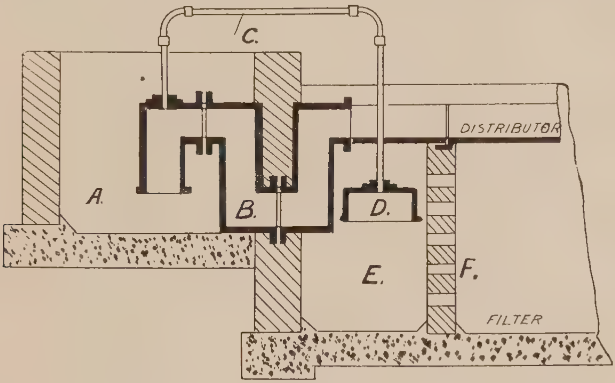


Fig. 314a.

Of late years they have practically supplanted contact beds on any but quite small works. The material used for the actual filter is the same as for contact beds. The walls of the filter may be solid, but, whereas this is a necessity in contact beds, it is merely a refinement in continuous filters, and is only adopted under special circumstances. It is more usual to build the walls of open (pigeon-hole) brickwork, which is not only cheap, but allows of very efficient aeration of the bed. In small works dry rubble answers the purpose very well. The only solid construction is then the base and the supports for the distributors. The former is invariably made of concrete, and must be laid with a fall to the point where it is desired to draw off the filtrant.

The most important consideration in the working of continuous filters is the method of distributing the liquor, for which there are various appliances on the market.

The essential conditions of the distribution are:

1. Uniform and fine distribution without exposing a large sewage area.
2. The slowest economical rate of travel.
3. Avoidance of freezing risks.

Uniform distribution is essential.

Ordinary perforated pipes have been used in some places with success. They want a fairly large head to work under, in order that a good spray may be obtained. There are one or two good forms of spray put on the market which, attached to ordinary cast-iron distributing pipes, work well if there is a good head. The most satisfactory form of spreader is the revolving type, of which many are in use at the present day. When the effluent is not good, however, when it comes from the tanks, but contains a large amount of suspended solids, those of the closed pipe type are very liable to chokage, and due provision must be made for thorough cleansing. These difficulties are obviated in the open-trough type. Fig. 315 shows details of such an open-trough spreader. It has the important advantage that all liability to smell emanating from sewage remaining in the arms is eliminated, as the perforations are made at the bottom of the troughs, and the liquid, being open to the atmosphere, assists in better oxidation thereof. Further, the centre of the spreader is fitted with special turbine guides, which assist in the rotation of the machine.

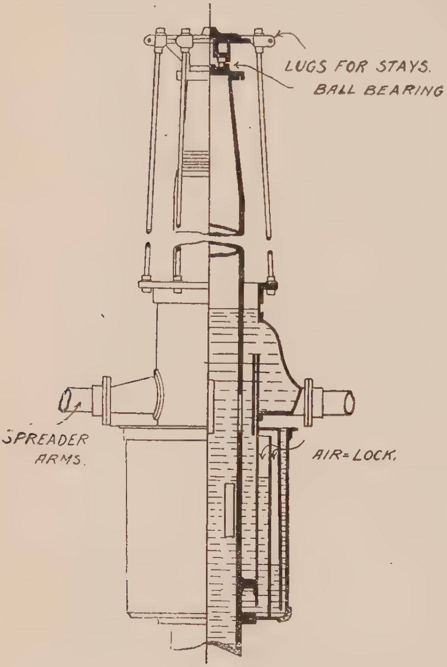


Fig. 317.

The pipe-arm type of spreader is shown by fig. 316. The particular one in question is of the continuous type; the sewage, passing up through the centre of the support, overflows into a revolving chamber, to which two of the arms are connected. Two subsidiary chambers are attached to the main chamber, and thus, when the sewage rises up to a certain level, it will overflow the weirs into these latter chambers, thus causing the arms attached thereto to come automatically into operation. This arrangement avoids the use of joints or seats, which are always more or less a source of trouble. Both sets of spreader referred to are fitted with two sets of ball bearings at the top cap, one to take the whole weight of the revolving portions of the spreader, the other to take up any side movement at the head. A set of roller bearings are fitted to take any side movement at the centre of the spreader, the rollers revolving around a special case-hardened steel ring fitted between the support and the flange of the centre; thus any wear which may take place is reduced to a minimum, and in course of time the ring can be renewed if required.

Another form of distributor of the same class made by Messrs Adams & Co. is known as the Cresset distributor. This is illustrated in fig. 317, from which it will be seen that the sewage passing up the duck-foot bend enters the slots shown in the central cast-iron column to the arms of the distributor. The head of liquid on the arms is the same as the source of supply; consequently there is no loss of head. The discharge under the maximum is three times greater than under the minimum; the volume delivered may thus vary in stock patterns from one to three; at the same time the discharge per yard over the total surface is uniform, a matter of considerable importance. The coupling is a simple air-lock trap, caused by the locking in of a body of air between the outer and inner annular spaces of the lower tank and the body of the distributor, which is suspended over and dips into the water-seal below. The air lock thus created allows the distributor to revolve practically without friction. At the same time it entirely prevents the exit of liquid through the coupling. The distributor body is hung upon a cross head and revolves around the central column upon ball bearings suitably carried, the whole being surmounted by a lubricator. The ball bearings and races may be removed and replaced without dismantling the distributor. This distributor may be fitted with open troughs or perforated pipe arms.

Another form of distributor is the Candy-Caink pattern.

These sprinklers differ in design from those hitherto adopted; each has an arm 95 ft. in length, and is supported at the centre and two points along the arm upon rollers moving upon circular paths, carried on concrete arches. The paths themselves are of glass, a material adopted as being non-corrosive and clean. The central pipe of the distributor forms one leg of a syphon, which conveys the water to the arm, which constitutes the other leg of the syphon. The syphon is of such a height as to afford a maximum head of 10 ft. upon the arms of the distributor, which enables the size of the arm to be reduced, and the entire distributor consequently lightened. This arrangement also saves the complications of regulating valves for preventing the distributors overflowing, and preserves the greatest simplicity.

Another advantage possessed by the syphon method of transmitting the water to the arm of the distributor lies in the ability to control entirely the operation of the filters from the engine-house. Any filter can be started or stopped by the man in charge of the engines without going outside the house, by opening and closing two small cocks. When it is borne in mind that the quantity of sewage to be dealt with is constantly varying, the importance of this advantage will readily be understood, as the necessity for increasing or diminishing the number of filters to be put in operation may occur at almost any moment, seeing that no storage capacity, strictly speaking, is provided, but that the water has to be dealt with immediately it is pumped. This advantage is secured by providing a small pipe up the centre leg of each distributor or sprinkler, and extending it to the engine-house; one branch of the pipe is opened to the air, and another is connected to the suction of the pumps.

To start a sprinkler it is only necessary to open the cock on the latter branch, when the pump will exhaust the air from the syphon and charge it. To stop the action, the other cock is opened, when the air immediately rushes in and destroys the vacuum.

In addition to this, the syphon method enables all or any of the distributors to discharge automatically the liquid on to the beds intermittingly if desired.

The rotating distributors are fitted with patent sprinkler jets, which have the effect of breaking up the streams of water into a fine spray, thereby exposing an immense water surface to the air for the absorption of oxygen, on which the activity of the micro-organisms, and therefore the purification, largely depends. The breaking up of the water into a fine spray also gives a better distribution of the liquid over the surface of the beds.

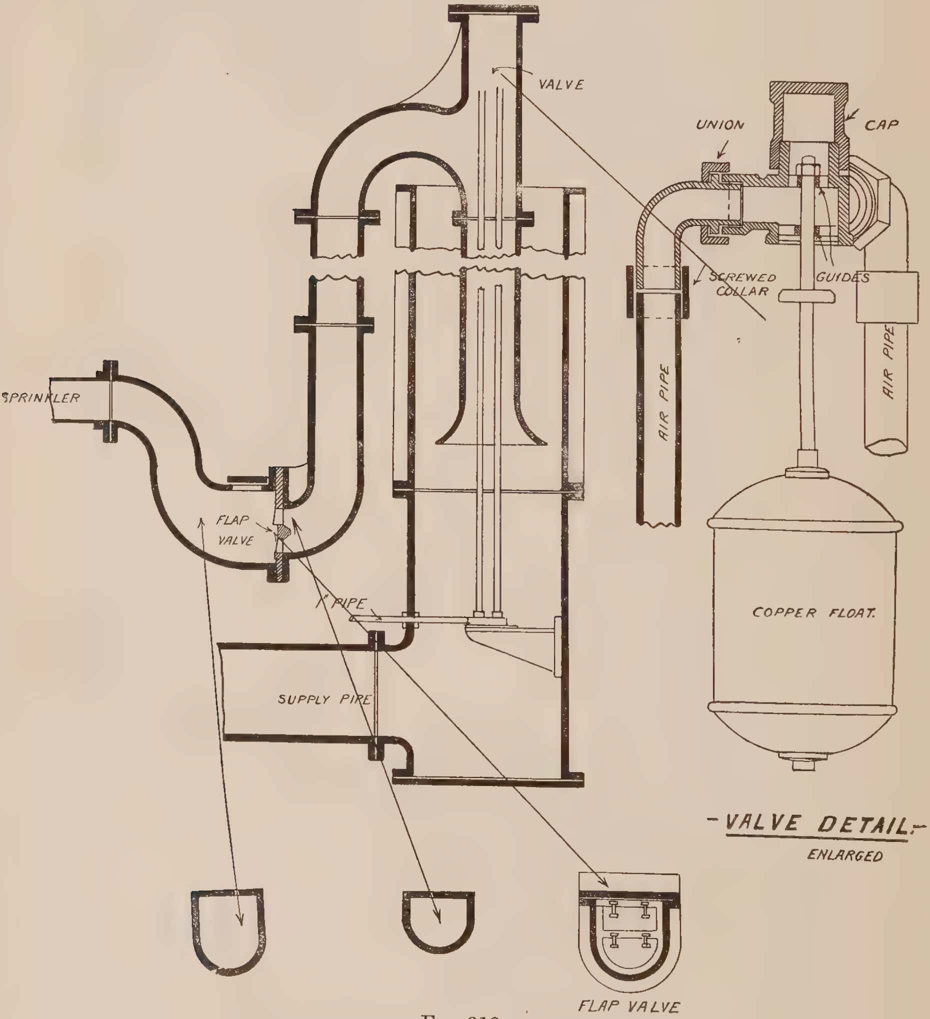


Fig. 318.

Details of the apparatus are given in fig. 318.

Spray Jets.—In some works the sewage is distributed on the beds by means of nozzles, set in pipes which pass over the beds and are supported at intervals on piers. They are only satisfactory in large units, and it is for this reason, and also that automatic distributors are unsatisfactory in small units, that contact beds operated by syphons are often preferable for small works. The spray system is in operation at Salford; the following details of it were kindly furnished to me by Mr Corbett, the borough engineer:—

"The tank effluent channels lead to a cross channel at the east end of the tanks, in which are 20-in. valves for supplying each of the roughing filters, six in all, which adjoin this channel. Each roughing filter has a row of inlet holes along its west end, supplied from a chamber in the wall below the cross channel. The floor is of perforated tiles on short legs, thus forming an outlet channel leading to an outlet pipe 20 in. diameter, controlled by a valve in the valve chamber; and from this chamber three 30-in. pipes convey the effluent to the aerating filters or bacteria beds.

"The roughing filter valves are arranged so as to provide for reversing the current in any one of the six filters, and thus 'upward washing' it, the washing passing to the sludge tanks or to the sewer as preferred.

"Also, for cleansing these roughing filters, each of the six is divided by screen walls into three bays, thus forming together eighteen bays, which can be 'upward washed' one by one. Each bay of about 105 sq. yds. area has a system of air-blowing pipes fixed near its floor, through which air is blown at a pressure of 5 lb. per sq. in., through 4800 holes of $\frac{1}{8}$-in. bore, thereby disturbing the gravel and speeding the upward flow of the washing water.

"These roughing filters are made of 3-ft. depth of fine gravel between $\frac{3}{16}$ in. and $\frac{5}{16}$ in. diameter. They have to be 'upward washed' and blown through once a day, or oftener when the flow of sewage is great. Their purpose is to remove matter in suspension and colloidal matter.

"The three 30-in. pipes above mentioned are along the north or upper end of the bacteria beds, with a 15-in. branch and control-valve to each of the fifteen beds first constructed, and with an 18-in. branch and valve to each pair of the beds subsequently formed. The 30-in. pipes have also valves at their inlets, so as to control the beds in three groups.

"When the first fifteen beds were designed in 1894 there was but little experience as to the durability of bacteria beds, so they were arranged with a strong tram rail supported on cast-iron pillars at each 31-ft. width, each alternate line of pillars also carrying a light tram rail at 2-ft. gauge from the strong tram rail, so that tram trucks of 2-ft. gauge might thereby bring the filtering material to its place. A light portable bridge with a turntable then carried the trucks across the width of a bed, so that the material could be dropped exactly where it was wanted.

"The strong rails were intended to carry a machine something like a steam-power travelling crane, by which the surface of the beds could be raked, or the material refilled into tram trucks and carried away for cleansing or renewal when required.

"The supply of clarified sewage to each bed passes through a 15-in. pipe at the base of the cast-iron pillars, and each pillar forms a rising branch up to a horizontal pipe 4 in. diameter, fixed above the surface of the bed, at 10-ft. centres, with six spray jets across the 31-ft. breadth of beds, each spray jet serving an area 10 ft. by 5 ft. 2 in.

"In the later constructed beds the tram rails are omitted, and the supply pipes are carried above the surface on brick pillars, with 3-in. branches right and left, so as to cover a double bed of 62-ft. breadth. All the distributing pipes have emptying valves and pipes leading to a sewer, to avoid risk of frost when resting.

"The filter floors are of concrete, with culverts at 32-ft. spaces for conveying the filtrate to the 4-ft. final outfall culvert at the south end of the beds. The concrete floors are covered with perforated tiles on legs 4 in. long, so as to provide ample ventilation below the beds. The earlier beds have ventilating manholes at each end of each culvert, and the later beds have vent shafts through the brick piers carrying their supply pipes; they have also open sides allowing free air-way to or from their raised tile floors, but the earlier beds are enclosed with walls. There are no dividing walls between the adjoining beds; they form really one continuous bulk.

"The filtering material is crushed cinders and clinkers, from about $\frac{3}{16}$ to $\frac{3}{4}$ in. in the earlier beds, and from $\frac{1}{4}$ to $1\frac{1}{4}$ in. in the later beds, with some coarser material at the bottom. Thirteen of the earlier beds are 5 ft. deep, two are 8 ft., and the newer ones are about 7 ft. deep.

"Owing to these beds having been worked for several years before the roughing filters were completed and provided with cleansing apparatus, there is much more clogging of the beds than was expected; but after they have been once thoroughly cleansed, it is expected that they will require but little renewal or cleansing in future years. Their surface is raked by hand labour each few days.

"The spray jets, when working under the full available head of about 8 ft., deliver at the rate of 50 gals. per sq. yd. per hour, or 1200 gals. per 24 hours if run continuously. There are 39,000 sq. yds. of beds, so each hour's flow of all the spray jets will discharge 1,950,000, say 2,000,000 gals. So, with the minimum or dry-weather flow of 8,000,000 gals. per day, each bay must be worked about 4 hours and rested 20 hours; and with the maximum flow provided for, fourfold the minimum flow, or 32,000,000 gals. per day, each bay must be worked 16 hours and rested 8 hours; but the working hours can be extended if desired by checking the flow by the control valves.

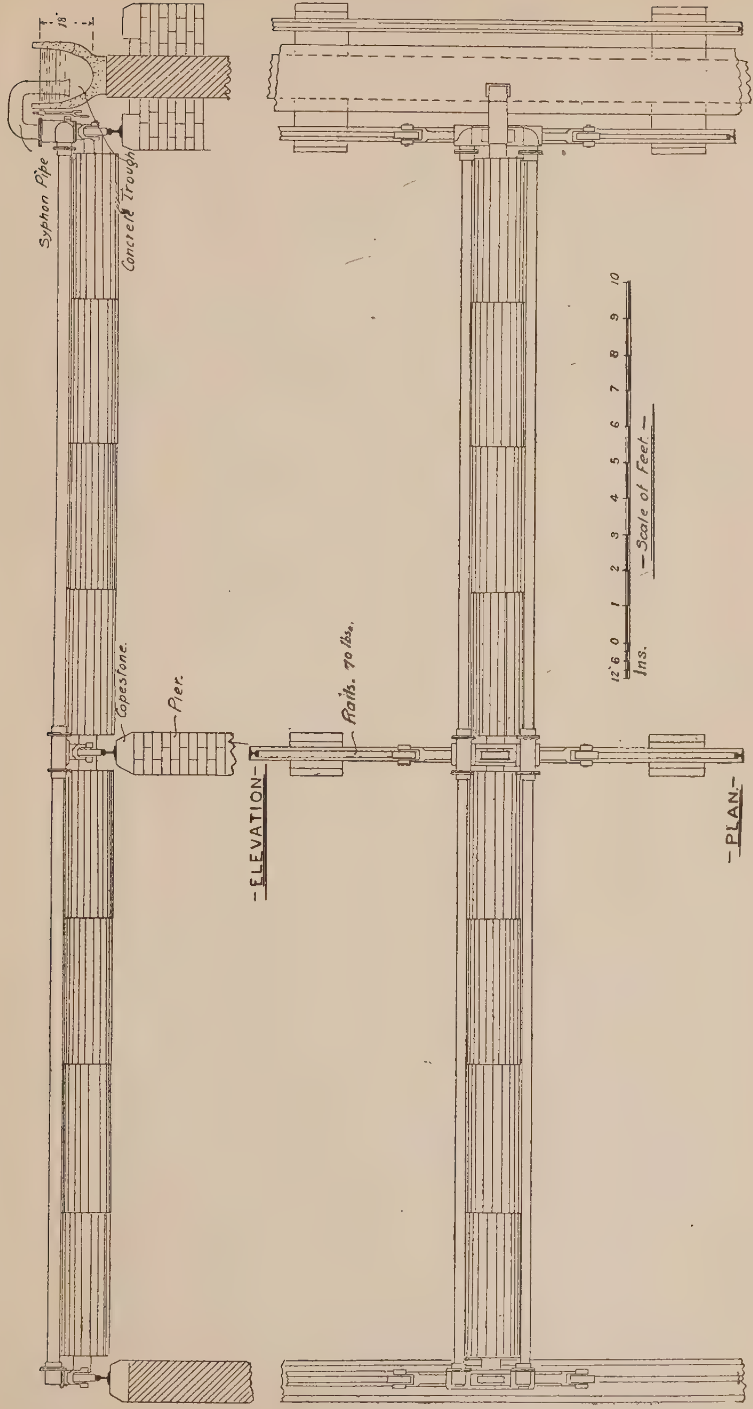
"It has been found best to run each bed for 2 hours and then rest it for 10 hours or less, according to the quantity to be dealt with.

"Thus the minimum daily flow per square yard of bed is about 205 gals., the average about 330 gals., and the maximum 820 gals.; but this large flow will only occur when the sewage is greatly diluted with rain-water.

"As the beds average 2 yds. in depth, these flows are only, per cubic yard of medium, 103 gals. per day minimum flow, 165 gals. average; and 410 gals. maximum flow when diluted with rain-water.

"The filtrate from these beds flows into the old culvert which formerly conveyed the intercepted sewage of the borough into the River Irwell before the sewage works were constructed; but the Irwell is now transformed into the Manchester Ship Canal."

Travelling Distributors.—In figs. 319 and 320 is illustrated a new type of distributor which has lately come into general use. The apparatus, which is simple in working, is on the principle of a water-wheel and runs on three rails. It is supplied from the effluent channel by a syphon pipe, which, when once started, continues to work without attention as long as there is any effluent to supply it. There is a patent automatic valve whereby the traveller, when it reaches the end of its travel, stops and reverses, and so on continually travelling backwards and forwards. This effect is caused by turning the liquid to the opposite side of the distributor.



FIGS. 319 and 320.

The water-wheel-driven distributor, as shown in figs. 319 and 320, is limited to relatively small beds, and on some works motion is effected by a small electric motor receiving its power from a "third rail." The more modern system is that of operation by cable. With this arrangement the distributor is moved across the beds by wire cables operated by a motor in a suitably located power-house. The system is quite simple, although the arrangement of ropes, clutches, reversing gears, etc., may call for a good deal of ingenuity in their laying out, especially in the alternate operation of adjacent distributors by one motor. By this means, however, very large areas can be controlled by one or two distributors, reducing the cost of the beds considerably.

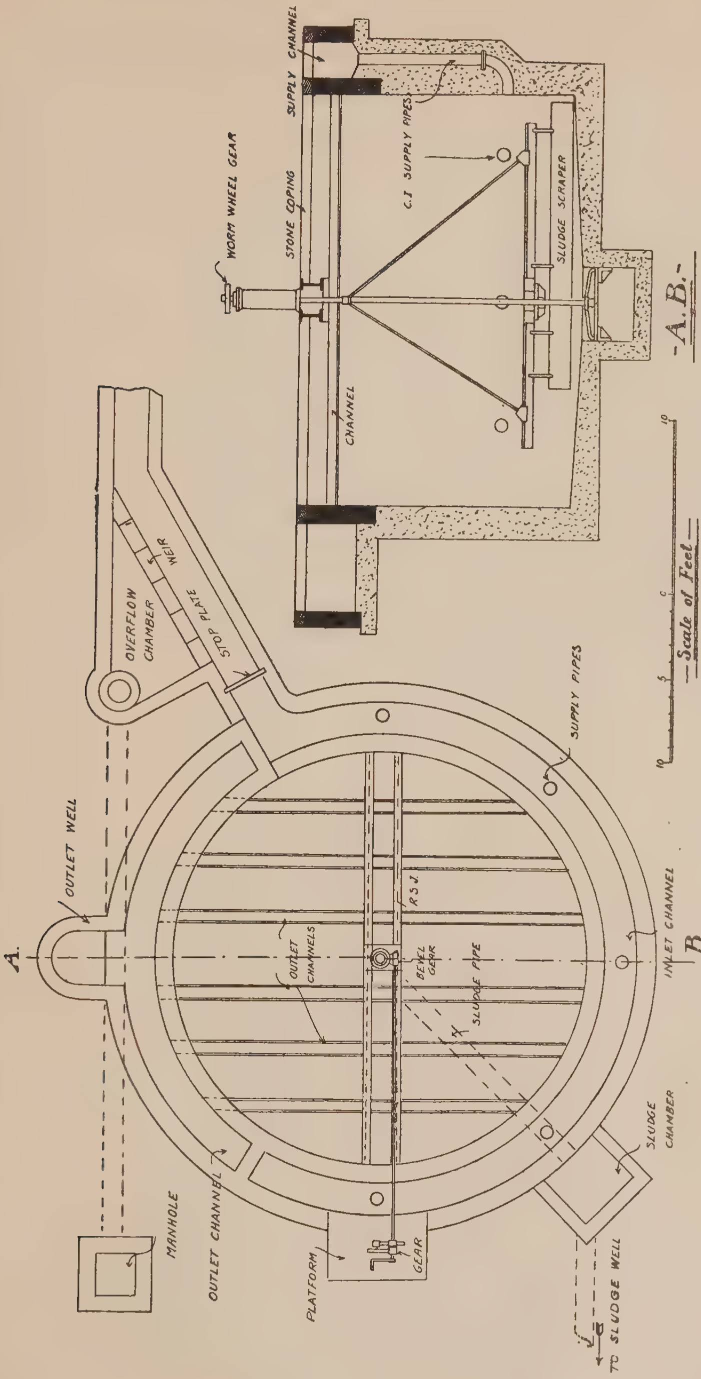
Lay-out of Complete Works.—In figs. 321 and 322 is shown a modern type of circular sedimentation tank, together with the necessary appurtenances. The screening chambers, which contain the gauging apparatus, etc., are not shown. It may be stated that all modern works have some sort of recording gear in order that the works manager may ascertain the volume arriving at the works, and hence the area of filter bed required.

It will be seen that the inlet pipes, which are of cast iron, are submerged and the tank provided with a helical scraper, which in this case is worked by hand, but may, as is often the case, be worked by electric motor.

Figs. 323 and 324 represent an example of a complete sewage purification works of large dimensions. Its details should be carefully studied by the reader. Sewage entering by the 15-in. channel is diverted to one or other of the detritus pits, being deflected in its course by baffle plates. Passing along, it flows through screens of the usual inclined bar type, and thence to the supply channel of the tanks. There is a weir in this channel which passes off the superabundance of liquid above the calculated quantity which is to be treated, and the remainder passes to either of the tanks by inlets controlled by hand-stop plates. Baffle plates are shown at entry, and scum plates at exit from the tank. The sludge is removed by gravity to the sludge tank shown, which has dry-rubble sides. The tank effluent passes off to the two farthest away filter beds, each 50 ft. in diameter by 6 ft. deep. It is distributed on to these by open-trough spreaders. The near bed, 41 ft. in diameter and 6 ft. deep, serves as a storm-water filter. All the filters have measuring valves. There is a connection from the detritus pit to sludge tank. The underground pipes are heavy iron, lead jointed.

Sludge Disposal.—When the sewage has been finally precipitated, either by chemicals or in septic tanks, there remains the ever-present difficulty of disposal of the sludge. In small works the production of sludge is not by any means abnormal and does not usually present much difficulty; but in large towns, where upwards of 1000 tons per day may be produced, and where land for disposal is expensive, and perhaps unattainable, then the subject becomes one of supreme importance.

The term "sludge" is usually held to designate that mixture of detritus and precipitated matter found after the passage of sewage through a tank. Septic tanks, on an average, produce about half the sludge of chemically precipitated tanks; this, then, will prove to be a very important factor in deciding what preliminary disposal treatment shall be given to the sewage. For instance, towns such as Dublin and Salford, which have direct access to the sea for barging out the sludge, employ chemical precipitation, which is rapid but produces a good deal of sludge. On the other hand, at Birmingham,



FIGS. 321 and 322.

where the sludge problem has produced some difficulty (but now appears to have been well overcome by the engineers), septic tanks are employed.

In septic tanks, no matter how efficient their working, it will always be found that there is a certain quantity of mineral matter which cannot be destroyed by bacterial action, together with some organic matter requiring a long time for its disposal. It is these two elements which make up the sludge in septic tanks. In fact, the idea formerly entertained, that septic tanks never want cleaning, has been proved to be a fallacy, at least so far as it concerns main-drainage works. It has been found in many cases of domestic septic tanks that they have not required attention for fifteen or twenty years; but the evils of over-septicising the tank liquor must be guarded against where further treatment of the effluent is concerned on a large scale, as already pointed out in the previous chapter. The amount of sludge produced at various works will, of course, vary under different circumstances. It is stated that [1] "with regard to the weight of wet sludge produced by precipitation, about 40 tons per million gallons, or a little over 1 gallon of sludge per cubic yard of sewage, is usually considered a fair average when it contains about 90 per cent. of moisture, but the quantity varies from 20–60 tons in individual cases, and the comparison of weight alone, without considering the percentage of moisture at the same time, is apt to be very misleading."

It is interesting to note also, as pointed out by the same writer, that if sludge is reduced from 95 per cent. of moisture to 90 per cent., its weight is reduced one-half, and if the moisture is reduced to 80 per cent., the weight will be one-quarter only of the original; in other words—

Let x be the weight of sludge after drying.
,, s ,, ,, ,, solids in 100 tons of sludge before drying.
P=percentage of moisture in sludge after drying.
Then

$$x=\frac{s\times 100}{100-\mathrm{P}}.$$

1 cub. yd. of sludge on an average weighs 16 cwt.

Now where the sludge is obtained by ordinary methods from the septic tanks and allowed to stand in sludge tanks for a short time to draw off any supernatant liquid, the most satisfactory method yet devised to deal with it is to cart it away to sea. This, of course, is only applicable to towns which have direct access to the sea and also produce enough sludge to warrant the purchasing and upkeep of a special boat for the purpose. The method employed at Salford exemplifies this. The following description of it has been furnished to me by the borough engineer, to whom I am much indebted:—

"Turning now to the disposal of the sewage sludge from the precipitation tanks, the floor of each tank slopes to an outlet pipe controlled by a valve in a subway below the central channel, and discharging into a channel along the said subway, and thence through an 18-in. pipe and a further length of open channel to the sludge tanks.

"Men with push-boards sweep the sludge across the tank floor to the outlet, wading in it with waterproof thigh-boots.

---

[1] *Sewage Disposal Works*, by Hugh P. Raikes, 1st ed., p. 148 (Messrs Constable & Co.).

"The outlet pipe in each tank has above it two 2-ft. lengths of cast-iron pipe, with valve seatings, so that the outlet is first used to discharge the supernatant water of the tank down to 4 ft. above the outlet-level.

"Then one length of pipe can be raised and the water run down 2 ft. above the outlet-level; and the flow along the subway channel is all this time turned into the main sewer. But when the second pipe is raised and the sewage sludge deposited on the tank floor begins to flow, the channel is connected to the sludge tanks.

"There are two sludge tanks, circular and saucer-shaped, 100 ft. diameter and 9 ft. deep in the middle, the two holding 3000 tons of sludge. There is a supply channel around each sludge tank, with holes through the wall to distribute the sludge. There is also a sludge-supply trough extending to near the centre of each tank. From the centre of the tank bottom an 18-in. suction pipe leads to the sludge pumps; and also at the centre is a 6-in. skimming pipe leading to the sewer, and fitted with a 'telescope pipe' and supporting float to skim water from near the surface, whether the tank be full or not. Thus the densified sludge sinks to the bottom, and the separated liquid is passed to the sewer, and so again through the tanks, etc.

"Between the two sludge tanks is the sludge pump-house, with two sludge pumps of 'Tangye's Special Pump' type, each with steam cylinder 16-in. diameter, double-acting piston pump 12-in. diameter, both 24-in. stroke, running up to about 35 double strokes per minute, each pump delivering about 200 tons of sludge per hour. These pumps work very satisfactorily, even when dealing with sludge containing 20 or 30 per cent. of solid matter.

"From these pumps an 18-in. pipe, 200 yds. long, conveys the sludge to the sludge steamer *Salford*, at a wharf on the Ship Canal."

With inland towns various methods are employed, of which the most usual are:

Pressing.
Drying, lagooning.
Trenching.

Disposing of the sludge, either crude or in the form of pressed cake, to farmers, or else using it on farms, are methods which have their advantages and disadvantages. In the former case the value of the sludge to the farmer depends largely upon the form of precipitant employed at the settling tanks, and even if suitable to their particular crops, they object to sending their horses and carts to draw with each load more water than manure. Lagooning of sludge is a simple matter if the land is available for the purpose. In this system a large shallow tank with earthen walls is laid out and very well underdrained. The drains are of the usual agricultural tile type, but the trenches are not filled in with the same material as was taken out of them (as this is used for the walls), but with very coarse sand, fine gravel, or engine ashes, which have been well washed and screened. The floor of the tank is covered with the same material; it requires renewal from time to time, owing to its disturbance when the sludge is removed. The sludge is simply conducted into these tanks, and when the liquid has drained away (some, of course, evaporates, especially in summer) it is disposed of in the most convenient way possible. The depth it is allowed to stay in the lagoon is usually 18 in. If there is no sale for it, it has to be buried in trenches. This process of lagooning may reduce the moisture by 25 per cent. It is certainly a cheap way of getting rid of the sludge, but in some places it may not be necessary to go to the expense of forming lagoons, especially if land is cheap and easily obtainable, the sludge being merely run into trenches, which are filled in, allowed to settle and dry out, and ploughed well. In hot weather the method may give rise to smell, and fresh land is continually required as the volume increases; it can only be used every second year, and not always then if the previous summer has been wet. Pipes must be laid to various points on the land used for this purpose, which is naturally a heavy first cost, the length being often great. Branches are left in the pipe to allow portable lengths to be coupled to it, which serve to convey the sludge to any convenient point, it being forced along the lines by air pressure. It is important also, when lagooning is employed, that the liquid from the drains, which is often foul, is treated on land or bacteria beds.

Where neither land nor other means of economical disposal of sludge are available, the only method is to press it in special filter presses, consisting of a frame on which are placed hollow ribbed plates of the form shown in fig. 325. When the two plates are put together a hollow space is enclosed, there being a circular opening in the centre. The clips at each side of the plate are to hang it on to the framework, and when they are in position pieces of canvas are placed between each pair of plates, thereby covering the entire hollow space enclosed. The plates are pressed together by power (usually hydraulic), and the sludge is forced into the machine, the solid matter adhering to the press cloths. The air pressure used for forcing the sludge is about 60 lb. per sq. in., and the sludge is mixed with lime beforehand, to make it cohere when in the cake state, in about a 4 per cent. proportion. The resulting cake occupies about $\frac{1}{5}$ the original volume of sludge. The cake, if kept dry, will not putrefy and does not smell; it may be sold to farmers, but more often than not has to be burnt.

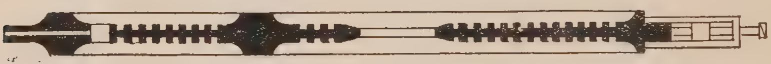


FIG. 325.

Attempts have been made to distil filter-pressed sewage as obtained from sewage-disposal works. Where filter presses are employed, and assuming the cakes of sewage can be obtained first hand, and in such a condition as to bear transit, then the process has for its ultimate object the production of oil, ammonia (as ammonia-water), and a solid residue which is to be converted into cement—for which purpose it is admirably fitted, especially where lime has been used as a precipitant in the separation of the sewage into sludge and effluent, as is the case in London.

The London "sludge" contains:

Moisture . . .	58·06	Nitrogen calculated as amm. sulphate 0·87 per cent. wet cake.
Organic matter . .	16·69	
Mineral ,, . .	25·25	

The mineral matter contains:

Carbonate of lime	7·94
Free lime	2·45
Silica	8·08
Oxide of iron	0·97
Alumina	3·39
Phosphoric acid	0·65

From mere inspection of the above results it will be seen at once that by simple drying of the sludge it would give a body capable, on distillation, of yielding ammonia, and also an oil of certain value as a carburetting material in the manufacture of gas. Experiments were first made on a small scale in the laboratory with pressed London sludge. Some promising results were obtained, and a small experimental retort was set up at Barking. The method of distillation was similar to that employed in Scotch shale works, the sewage being thoroughly dried before distillation. The following particulars are from a paper read before the Institute of Civil Engineers in Ireland by Mr F. Marmaduke Purcell, vol. xxviii:—

"TABLE XXIX.

Wet Cake from	Ammonia Sulphate.	Residue.	Oil per ton.	Water.
Crossness	57·56 lb. per ton	39·00 per cent.	7 to 11 gals.	54·10
Leyton	59·80 " "	68·40 "	9 to 10 "	52·00
Wimbledon	65·63 " "	56·00 "	5 "	51·00

"In carrying out these experiments I found that it was necessary that the cake should be nearly dry (not containing more than 15 per cent. of water) before it enters the retort, and for this purpose the waste heat from the retorts would be economised, and also the gas evolved during the distillation; even if extraneous heat had to be applied, the cost thereof would not equal the cost of mining the shale, which amounts to four shillings per ton; and therefore if we obtain from the sewage products which are as valuable as those obtained from the ton of shale, the process still remains on a remunerative basis.

"The oil obtained is neither so large in quantity nor so good in quality as crude shale oil, and would not be worth more than 1½d. per gallon, for carburetting purposes, but the yield of ammonia would be nearly double that obtained from shale, whilst the residue when ground would certainly be valuable as a cheap cement, and quite good for the purpose of making concrete.

"The yield of one ton of sewage cake containing say 15 per cent. of water would be roughly as follows:—

	s.	d.
20 gals. crude oil at 1½d. per gallon	2	6
80 lb. ammonia sulphate, 1½d.	10	0
10 cwt. of residue suitable for cement	5	0
	17	6

"The cost of obtaining the above would approximately be as follows :—

	s.	d.
Drying 2 tons of sewage cake, say 2s. per ton for coal used in addition to the waste heat derived from retorts	4	0
Cost of distilling and producing the crude oil and ammonia	4	6
Cost of crystallising the sulphate of ammonia, and cost of sulphuric acid necessary	2	6
	11	0

"The amount of ammonia is taken at much less than that really obtained from the process, even when working with a very imperfect apparatus, and the value of the residue is certainly taken at a very low figure. The proper method of really testing the process would be to erect a bench of say ten Young & Bilbey's retorts, capable of passing about 30 cwt. or 2 tons of shale in 24 hours each. With sewage, very possibly a little more might be got through.

"The cost of these may be taken at from £55 to £65 each, and there is no doubt that by the use of these retorts a much higher yield of ammonia would be obtained.

"Following up my own experiments, I had a consignment of pressed cake sent from Glasgow to a large shale-oil works, where, by the courtesy of the heads of the works, they carried out a distillation for some of the pressed cake in their experimental works with most satisfactory results, as you can see from the return they certified to me from their tests. The results they got were as follows from the cake as received :—

Moisture	71·335
Organic matter	10·210
Ash	18·455
	100·000"

At the same time it may be definitely said that commercial processes for extracting the more useful constituents of sludge have on the whole failed, and the progress being made with sewage disposal by the activated sludge system makes it unlikely that further progress will be made in this direction.

The Activated Sludge System.—Since the first edition of this book was printed a considerable advance has been made in the treatment of sewage by the activated sludge system. So far as one can judge it is applicable to most cases, and involving relatively simple and inexpensive works, and producing very little sludge for final disposal, the system would seem likely to supplant the older ones as time goes on.

As opposed to the systems previously outlined of tank precipitation involving the action of anaerobic bacteria and treatment of the tank liquor on beds wherein aerobic bacteria complete the purification process, the activated sludge method is a single process of elaborated tank treatment which, involving the circulation among the fresh sewage of activated sludge, depends wholly upon the influence of aerobic bacteria. It is so arranged that the effluent may without further treatment be turned adrift without risk of secondary decomposition. The sludge problem is also simplified. A certain proportion becomes digested, and what remains to be disposed of is free from smell, relatively rich in nitrogen as compared with ordinary settled sludge, and is acceptable to farmers, who are usually willing to pay for it.

The first stage in the process lies in the cultivation of bacteria by the aeration of the sewage in open tanks, which causes the activated sludge to maintain its activity and so to perform its duty of coagulating the colloidal matter in the crude sewage. This is then allowed to settle, during which time the coagulated matter and the suspended matter are precipitated.

While the theory of the process may be somewhat involved, the principle itself is both a simple and a natural one, and merely an intensification of the purification which is effected on foul water caused to pass down a swift, rough river channel. The engineering side, therefore, lies in devising methods to effect the necessary agitation and aeration.

Elements of Design.—While the process would appear to have originated in America, practical developments are in the main due to Drs Fowler and Ardern at Manchester, where the necessary facilities were afforded by the Corporation. Since then a number of devices have been put forward, and some have been tried out, and served the purpose of experiment and eliminating inefficient methods. Those now surviving take the form of treatment in tanks wherein the sewage is mixed with the necessary ripe sludge and agitated by air bubbles, or the passing of the sewage along relatively long narrow channels in which it is propelled and agitated by mechanical means. The former method may be briefly outlined as follows:—

After removal of heavy grit and large floating solids in detritus pits the sewage is passed through a coarse screen into a circular disintegration tank, in which all solid matter is broken up into smaller particles. Disintegration is induced by the blowing of air bubbles through the sewage from porous stone diffusers fixed in radial channels in the base of the tank. After the solids have thus been mechanically broken up the sewage flows through a fine screen into a grease interceptor, and thence to the mixing chamber. This contains a percentage of activated sludge, which having been previously aerated is mixed with the incoming sewage by means of diffusers. The actual purification is accomplished in the aeration tanks, along the length of which are air diffusers. The solids are thrown down as activated sludge, still kept in constant agitation until final settlement in pyramidal tanks.

Actual construction of a plant will be dealt with presently. In the meantime, numerous full-sized and laboratory experiments have been carried out. Salford, for instance, the adjacent but quite distinct borough to Manchester, tried out two types of tank, one in the form of an endless channel and the other as a "once through" tank, rectangular in shape, with a ridge and furrow or saw-tooth bottom. Subsequently at Stamford, Worcester, and Leicester further plants were erected, which finally demonstrated the superiority of the "once through" tank as being cheaper both in first cost and operation. Then came consideration of the best arrangement for the diffusers and cross section of the tank, and the present arrangement is depicted in fig. 326, it being presumed that the sewage is flowing towards the observer on one side and back on the other. The position of the diffusers is found to give the tank contents a spiral motion, while the rounded corners are regarded as very desirable. Another improvement effected has been that of the inlet to the conical settlement tanks in the shape of the arrangement shown in fig. 327, which is designated as the Clifford inlet, being due to Mr William Clifford of Wolverhampton. Its object is to ensure the minimum of disturbance of the sludge in the settlement tank.

A Typical Plant.—The lay-out of a typical plant is shown in figs. 328 and 329. The sewage entering at *a* passes the usual form of screen *b* into the disintegrating tank *c*. Therein are placed radially the diffusers *d*. These are formed of porous stone troughs through which air is forced, and they are placed on the tank bottom. The treatment herein is for the breaking up of the solid matter only. Down the central well *e* the sewage passes *via* a fine screen arrangement in the form of a grease interceptor, from which any grease can be withdrawn from the top and the sewage then enters mixing chamber *f*. There it is mixed with activated sludge from channel *g*. The amount admitted varies according to conditions—it is usually from 15 to 30 per cent. of the sewage volume. It now passes along the aeration tanks or channels *h*, which are of the form shown in fig. 326, and across which are baffle walls *j*, in which there are openings shown by *a* in fig. 326. During the tank treatment, which averages six hours, air is freely circulated through the diffusers at the rate of about 8 cub. ft. per square foot of tank area per hour, and at a pressure of about 5 to 10 lb. The exit from the tank is at *k*, where the purified sewage passes *via* pipe *l* to the Clifford inlet *m* of the conical bottom settlement tank *n*. Generally one hour suffices to settle the liquid, which can then be run off. It will be seen that, due to hydrostatic pressure, the sludge is being constantly forced up passage *p* into channel *q*, in which there are also aerators, and thence back to *g*. Surplus sludge is run off as required.

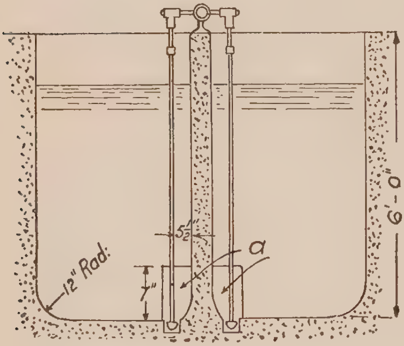


Fig. 326.

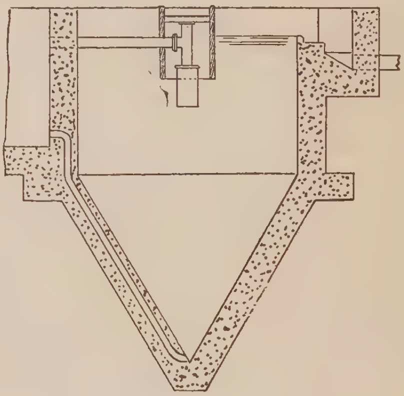
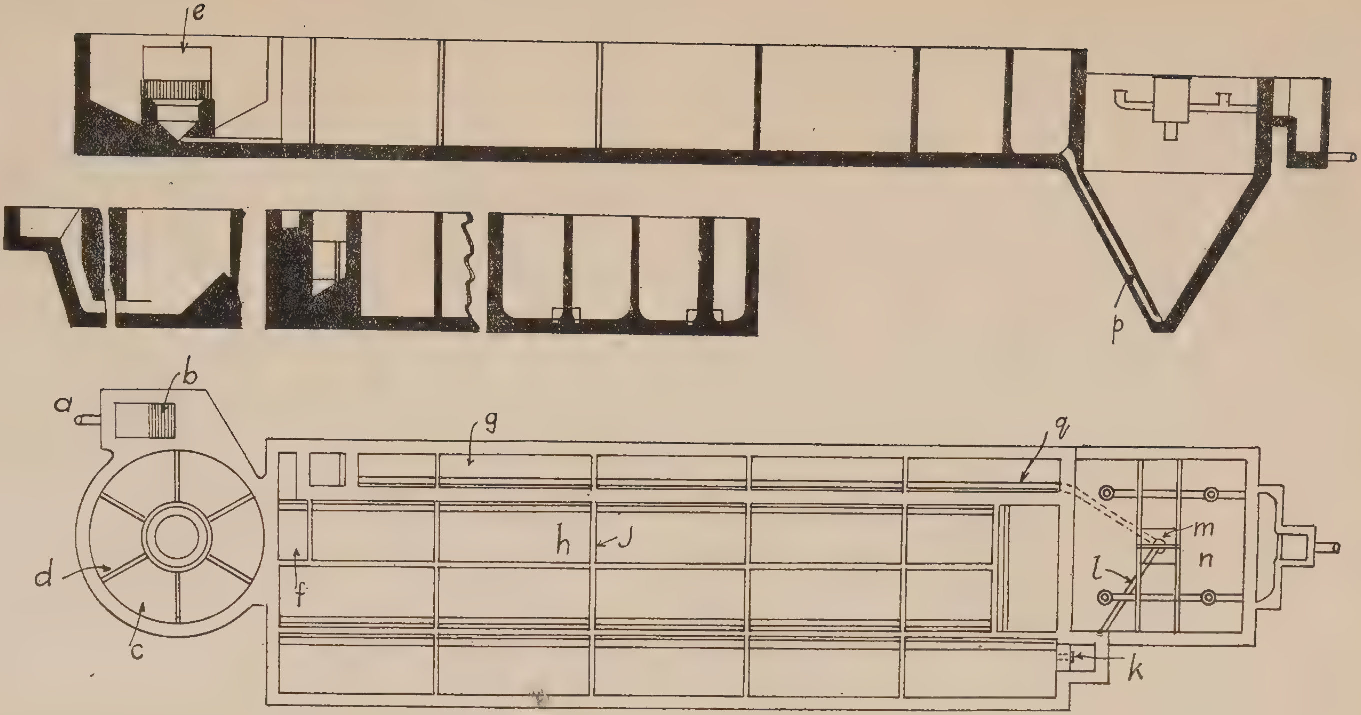


Fig. 327.

Plant in Working.—The foregoing description shows the essential equipment as now regarded as accepted practice, modifications naturally being introduced as further experience is being gained. Progressive developments are being carried out by the Activated Sludge Company.



Figs. 328 and 329.

a, Inlet sewer.
b, Coarse screen.
c, Distegration tank.
d, Diffusers.
e, Grease-collecting chamber and fine screen.

f, Mixing chamber.
g, Reaeration channel.
h, Aeration channel.
j, Division walls.
k, Restricted orifice.

l, Feed pipe to Clifford inlet.
m, Clifford inlet.
n, Settlement tank.
p, Sludge return to reaeration.
q, Sludge-return pipe.

Plants are designed for as small a flow as 5000 gallons per day. There are now in operation, amongst several others, installations at

Manchester	1,000,000 gals. per day,
Hanley	,, ,, ,,
Burslem	,, ,, ,,
Coventry	2,000,000 ,, ,,

while at Reading a recently erected plant has a capacity of 3 million gallons per day.

Reading, it might be mentioned, is one of the very few places sewered on the separate system, and the sewage has been previously dealt with at a sewage farm. The Ministry of Health have approved the scheme, which is designed to treat 3½ million gallons per day from a population of some 90,000, with a probable increase to 120,000. After being screened, the sewage meeting the required volume of activated sludge is raised by air lift—air-lift pumping is regarded with special favour in this connection—to the first aeration tank. The sewage passes through the four aeration and connecting tanks in sequence, these being essentially of the type already described. The conical-bottom settlement tanks are also of the usual form, having four conical sumps each. They are used alternately. The sludge passes to reaeration tanks, the surplus being drawn off to the sludge tank. This is another conical-bottom tank for the purpose of concentration of the surplus sludge, from which the supernatant water is continuously drawn off. The plant is so laid out that in operation all the tanks can be completely emptied at any time, the liquid being handled by air lifts and the sludge by ejectors, the ejector chamber being beside the sludge tank. Every aeration and connecting tank can be filled with final effluent by an independent air lift, this effluent forcing out before it the previous contents, leaving the unit full of effluent, when aeration can be stopped. By this means the number of aeration units in operation can be reduced, the sludge from such units being concentrated in those tanks in operation. The tanks out of commission standing full of aerated effluent can be brought into immediate operation if an increased flow or increased strength of sewage demands a longer period of stay. During several hours at night in dry weather when the flow is small and weak, this flow can be accommodated in the empty stand-by unit and the aeration machinery stopped.

The following are the principal advantages claimed for this system of sewage treatment:—

1. Rapid purification with a fully oxidised effluent free from smell, flies, and liability to putrefaction.
2. Inoffensive sludge of good manurial quality.
3. Minimum loss of head.
4. Small attendance and maintenance charges.
5. Low capital cost—at present about 12s. 6d. per head of population provided for.

Working of the Process.—The activated sludge process works upon a principle identical with that of the contact bed, but whereas the latter operate at low efficiency due to the formation of humus and large lumps, and to the area of contact between sewage and air being small, activated sludge aims at higher efficiency by the intimate mixing of bacterial cultures and artificial aeration by the diffusers. This aeration is continued till chemical tests show that all the ammonia in the sewage has been converted into nitrates. The sludge which rapidly settles when the air is turned off is activated sludge, and is an aerobic bacterial culture. It is essentially different from septic-tank sludge, and it is inoffensive. If this sludge is left in the tank and the latter again filled up with sewage and aerated, the nitrification of the second filling will take place rather more rapidly, and so on with each filling till, with the tanks about one-quarter full of ripe sludge, complete nitrification takes place in a few hours. This getting-to-work process may take some weeks unless suitable sludge is available from another works to effect a start. The purification of the sewage would appear to take place in two stages. The first is a rapid carbon oxidisation process, in which the organic matter being broken down, the carbon is converted into CO_2. While after this action the liquid will be found to be stable, the aeration is continued, so that nitrate may be formed in the liquid and to ensure that the effluent shall be non-putrescible. The sludge produced at the rate of about 42 tons per million gallons is dark brown in colour, smells merely earthy, and contains some 98 per cent. of water. It is rather difficult to dry, but if lagooned on cinder beds it is spadeable in about four days. As stated, it has a good manurial value containing from $3\frac{1}{2}$ to 7 per cent. of nitrogen.

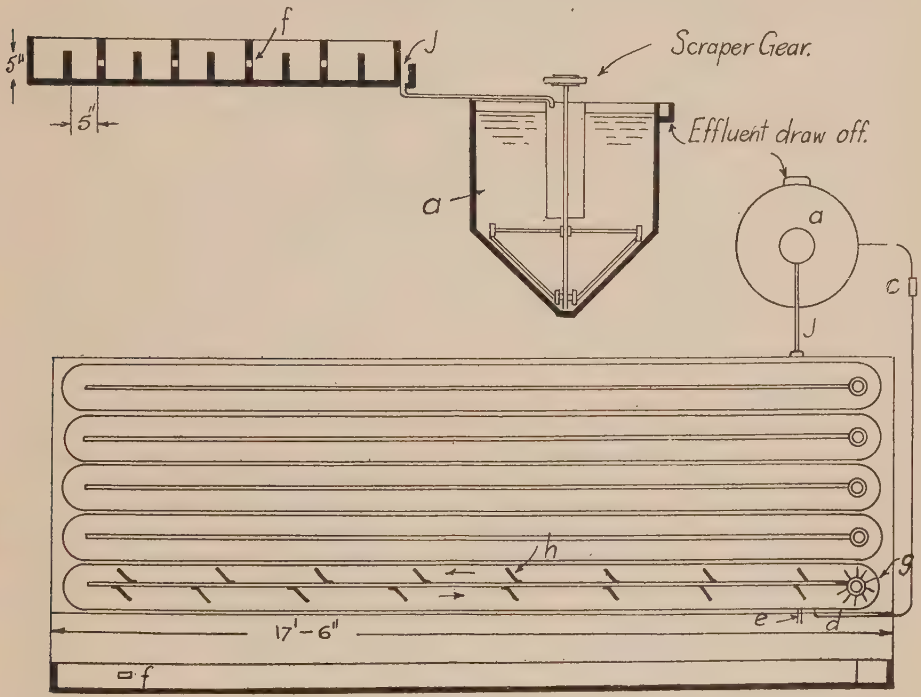


FIG. 330.

The effluent is relatively clear, it is free from colloids, and will pass any test prescribed by the authorities in this country. As non-putrescible effluent and inoffensive sludge are the ultimate aims of all sewage-purification methods, the system appears to have well justified its introduction, and as its cost both in installation and working compares very favourably with other methods, considerable extension thereof may be looked for in the near future.

Mechanical Agitation.—The latest developments of this process make use of mechanical agitators to effect the artificial aeration and circulation essential to the process. This method is based upon the well-known fact that foul water flowing down a rocky river channel becomes purified by the natural agitation to which it is subjected. The practical application of the principle to sewage treatment at present takes the form of passing it through long, narrow, shallow channels, along which it is forced by paddles.

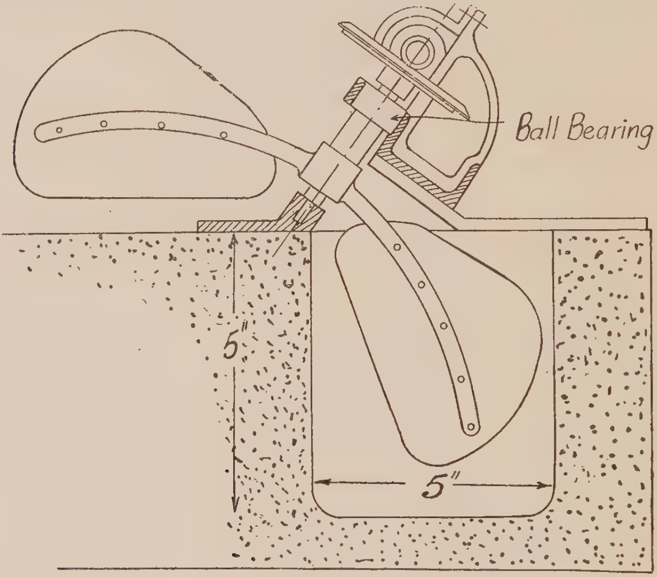


Fig. 331.

The idea is shown in fig. 330. The settling tank *a*, it will be noted, is fitted with a sludge scraper *b*. This revolves about once in fifteen minutes, so as to maintain in circulation about 90 per cent. of the sludge. This is taken in hand by the pump *c* and delivered at point *d*. At the point *e* the sewage enters the first of the channels, which are interconnected by ports *f f*. At *g* are situated the paddles for agitation. These, in the particular plant referred to at Hanley, Staffordshire, are of the form shown in fig. 331, which is claimed to be much superior to flat-bladed paddles mounted on horizontal shafts previously used. At intervals along the channel are disposed baffles at about 21-in. centres and set at 45° to the direction of flow. These force the liquid to take a spiral course, which not only keeps the sludge in constant suspension, but also brings it continually to the surface for the purpose of aeration. The velocity of flow maintained is 30 ft. per minute. There are quite a number of different methods at present being tried out for effecting the same end—that is, circulating sludge through the sewage and aerating it—but no definitely standardised method has yet been evolved. That illustrated above appears to be one of the most practical, and has the advantage of absorbing very little power and only calling for equipment of a very simple nature. It is known as Hartley's Bio-Aeration process.

CHAPTER XII.

SPECIAL CONSTRUCTION.

In this chapter some notes will be made of special constructions which have occurred, and are likely to occur, in the carrying out of a main-drainage scheme.

The first and perhaps most important problem is that of crossing rivers and other natural or artificial depressions of the surface which present themselves in the line of a sewer. The methods of tunnelling under railways, canals, etc., have already been dealt with.

One of the most usual ways of carrying a sewer across a river or canal is to syphon under it. This method has been employed in many places and has generally proved successful. The use of large syphons is often necessary for conveying the whole of the sewage from one-half of a large city divided by a river in order that it may all go to one main outfall works. This is the case, for instance, in Dublin, whereas in Glasgow and London there are two main outfall works. It is also very often the case where main sewers are concerned, as was pointed out in a previous chapter, that the invert is below the level of water in the river, which puts the question of carrying it over impossible, and hence the only remaining solution of the problem is the inverted syphon. The simplest case is illustrated diagrammatically in fig. 332, the sewage flowing down one side and up the other.

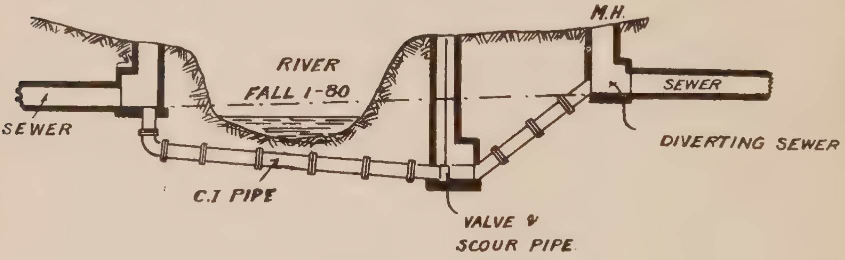


Fig. 332.

The first essential condition is that there must be a certain difference of level between the invert of the syphon at the inlet and outlet, in order that there shall be a self-cleansing velocity in the syphon, which is considered as a pipe running full, under a pressure equal to this head. For the calculations affecting this the reader is referred to Chapter II. Obviously the greater the fall the better. In the entrance manhole it is wise to place a storm overflow, because not only is the position very suitable, but the expense of construction will be somewhat reduced by the consequent reduction of capacity to be provided for, although in this connection this is not a very important matter, there being nearly the same amount of work in laying down a small syphon under these conditions as is required for a large one. At the very lowermost point of the pipe line another manhole is constructed containing a sluice valve and a scour valve. This latter serves to empty the pipes when required, the liquid flowing into the chamber. From this it may have to be pumped more often than not; but if the river has a weir lower down, a gravity pipe may serve the purpose if sufficient fall is available. The syphon pipes should be of such a size that with the available fall a self-cleansing velocity is maintained with the ordinary dry-weather flow; and in order to provide for rain-water up to three times the D.W.F. it is expedient to place duplicate pipes, which would come into action when the other is discharging at its utmost capacity. A valve may also be placed in the entrance manhole to serve the purpose of damming back the sewage for a short time, and then letting it off suddenly to scour out the syphon; but the good results which might be expected of this method have not been fully realised in practice.

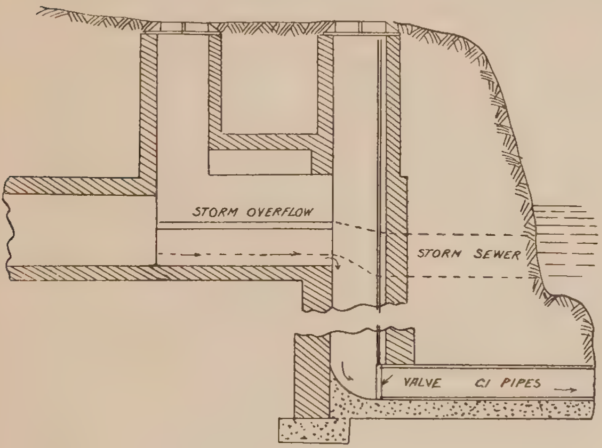


FIG. 333.

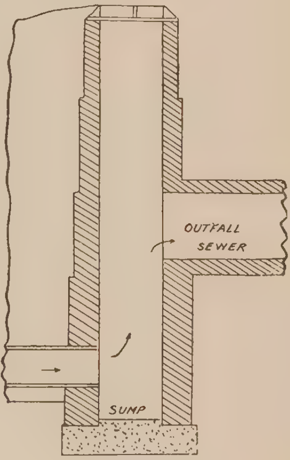


FIG. 334.

In the case of navigable rivers and ship canals it may be necessary to carry the pipes considerably lower than shown, in order that future dredging operations may not disturb the work, while the character of the bed of the stream is also a very important determining factor. Hence borings must be carried out. In all cases it is wise to go down to impervious strata if at all possible. In fig. 332 the syphon is shown with inclined pipes, but they are often constructed, as shown in fig. 333, with two vertical shafts, one on each side of the river, and a gradually sloping connecting pipe. In either case it is wise to introduce a rough screen in the entrance manhole to intercept heavy solids.

It may be remarked that the construction shown in fig. 332 is preferable when considering the syphon having a self-cleansing velocity, as it is not so likely to give trouble in this direction, the pipe being the same diameter from inlet to outlet, while in fig. 333 the vertical shafts tend to arrest the flow. On the other hand, if a sump is sunk in the outlet shaft of the syphon as in fig. 334, much of the solid matter will be intercepted, and can be easily removed therefrom.

In fig. 335 is shown a method by which the pipes are laid over small streams not used for navigable purpose, and when the excavation below the bed is not deep. When, however, the river is large and navigation must not suffer any interference, the method of procedure is by tunnelling under compressed air, as already discussed, and laying the pipes in a culvert formed of cast-iron segments. The system of laying the pipes in a dry culvert, where they can be inspected and repaired at any time, has always commended itself to waterworks practice, where the pipes are under considerable pressure, and is now considered to be highly desirable in the case of sewerage schemes, although the expense may be somewhat heavier. On the other hand, the culvert always affords a convenient passage for water mains, gas mains, and electric cables, although with gas mains there is always a risk of explosion, due to leaks, unless every possible precaution is taken to ensure sound joints and thorough ventilation.

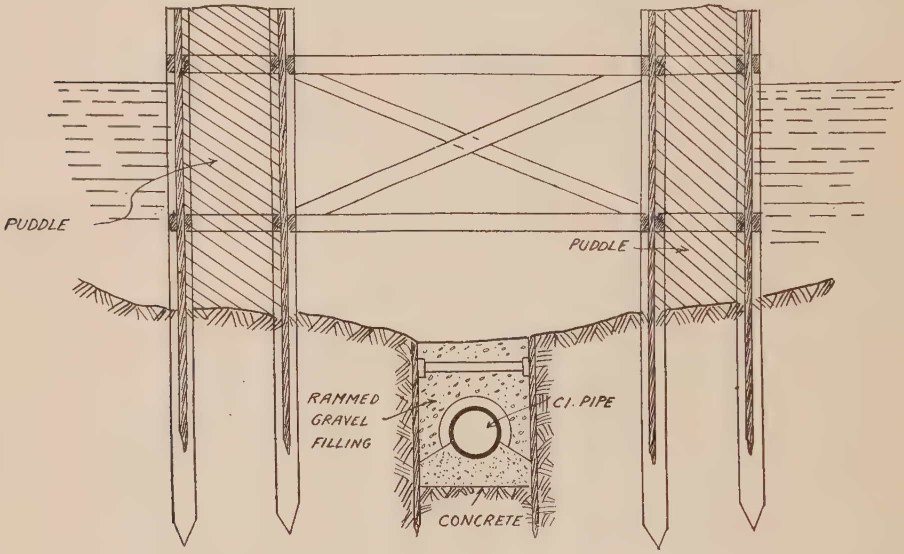
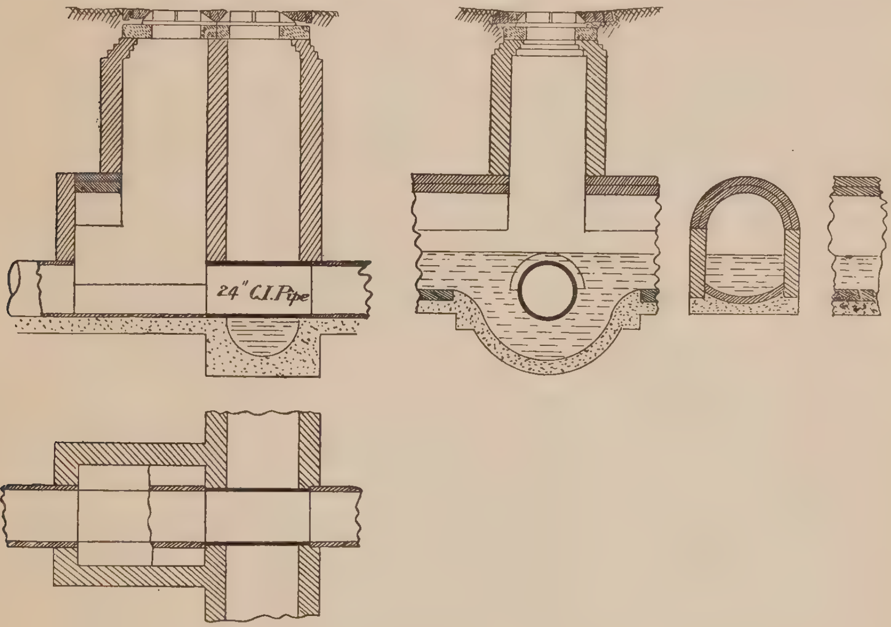


FIG. 335.

In fig. 336 is shown details of a cast-iron syphon pipe of large dimensions, which forms part of the Dublin Main Drainage Works.

At Eden Quay the sewage of the north side is passed under the Liffey by means of this syphon, which is 3 ft. 4 in. in finished internal diameter. It was constructed by means of a tunnel driven in the solid rock from Eden Quay to Burgh Quay. Cast-iron pipes were then laid in the tunnel and the space between the pipes and the rock filled with concrete. The pipes were lined with blue brick in cement. On the whole, the work is a good example of its kind and typical of the latest practice.

With small and unimportant streams it may be the case that the sewer crossing should be considered as the obstacle to be overcome—that is, the bed of the stream would be lowered and carried under the sewer, which preserves its gradient. In a small stream having a rapid fall, this will no doubt be the best way. The construction may be that of an inverted syphon under the sewer of shallow depth, or if backing up of the water for some distance upstream would have no evil effects, a weir could be placed across the river, built of concrete, and cast-iron pipes placed in it. Its external shape and other construction would be that of any other weir, always bearing in mind the necessity of letting the water over the crest as gently as possible. The subject is treated in *Civil Engineering Practice.*



FIGS. 337, 338, and 339.

Figs. 337, 338, and 339 show an alternative system.

The invert of the sewer is about a foot below the bed of the brook. As this watercourse drained a considerable area, it was necessary that the sewer should not raise the level of the water or interfere with the flow of it.

The work was further complicated by the fact that, as the sewer was to be laid in a new thoroughfare, it was necessary to culvert the brook where it passed under the street. The size of the culvert was decided by that of an existing one, which was controlled by sluice gates at the point where the small stream joined the main watercourse. As the drawings show, this culvert, which is in brickwork, is 4 ft. high by 3 ft. wide, and in order to supply an equal or slightly larger water area it was given a semicircular or domical invert 18 in. deep, which allowed water to pass freely under the sewer when the brook was low, and both over and under in a storm. A double manhole was provided—one, the ordinary manhole, for inspecting and clearing the sewer; the other to allow the bed of the culvert to be cleaned out if necessary. The cast-iron pipe, though somewhat of the nature of an obstruction, would not in practice prove so, being circular and smooth, and having a good waterway underneath.

Carrying of Pipes over Rivers.—As an example of this class of work take a 30-in. cast-iron pipe, flange joints laid over a river, 60 ft. wide, at a height of say 4 ft. above maximum flood-level.

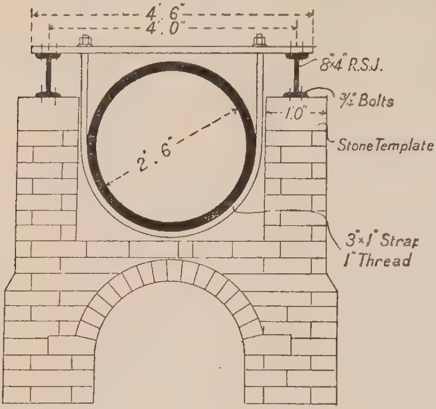


FIG. 340.

Referring to figs. 340 and 341, the piers, four in all, are placed 20 ft. apart. They would be made of masonry, brickwork, or concrete.

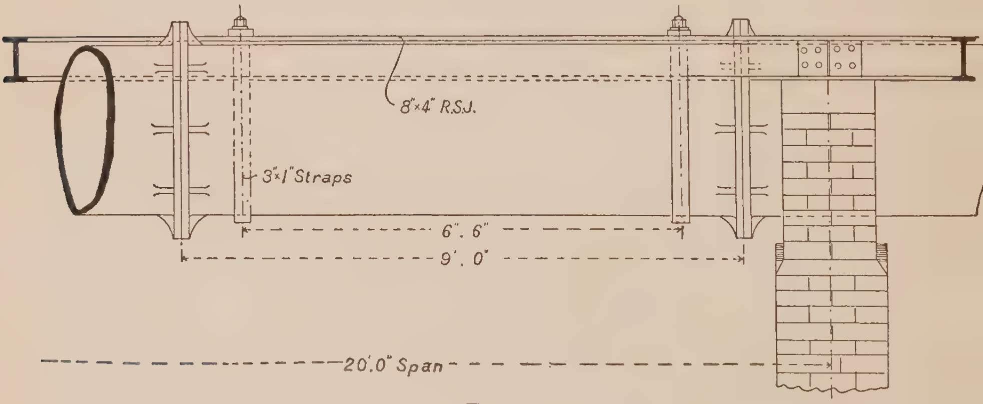


FIG. 341.

Looking up a table of cast-iron pipes, one finds that a 30-in. water main, tested to 300-lb. pressure, weighs 3·29 cwt. per foot-run, and 3·29 cwt. × 20 = 3·29 tons (say 3·30 tons) between each span. Again, the sectional area of a 30-in. pipe = 4·91 sq. ft., and × 20 = 98·2 cub. ft. capacity. Taking water at 62·5 lb. per cub. ft., the weight full is equal to 98·2 × 62·5 = 6137·5 lb., or say 2·8 tons, or 3·30 + 2·80 = 6·10 tons total load. Referring to any table of properties of rolled steel joists, it will be ascertained that to support $\frac{6 \cdot 1}{2}$ tons (= 3·05 tons), two 8-in. × 4-in. I beams could be used, with a supporting capacity of 7 tons, or nearly 1 ton in excess. These, however, would be the most economical sections to use. The weight of these joists per foot-run is 18 lb., ∴ the total weight of the superstructure is $(6 \cdot 10 \times 3) + \frac{(18 \times 120)}{2240}$ tons = 18·3 tons, or, allowing for contingencies, straps, etc., say 19 tons. This is distributed over four piers, the two middle ones of which will each bear about $6\frac{1}{2}$ tons and the two outer ones $3\frac{1}{4}$. This will fix the area of the piers and foundations. The construction is shown detailed and dimensioned.

To illustrate another method, assume a 9-in. (spigot-and-socket) pipe laid across a river, the span from centre to centre of supports being 50 ft. Fifty ft. of 9-in. water main, including sockets, weighs (if of $\frac{1}{2}$-in. metal) 2610 lb., assuming it to be made up of 9-ft. lengths at 47 lb. per foot-run, each socket being equal to 1 ft. of pipe. The water in the pipes will weigh 1352 lb., by the rule of a gallon of water being equal to 10 lb., and the number of gallons per yard in any pipe being equal to $1-10d^2$ (d=diameter in inches). Therefore total weight=2610+1352=3962 lb. A good economical way of supporting this pipe would be to lay a rolled-steel joist of suitable section with flanges vertical, so forming a trough in which the pipes would lie. Looking up a table of joists again, a 12-in. × 6-in. × 54-lb. I beam would be selected. Testing the assumption by the familiar equation

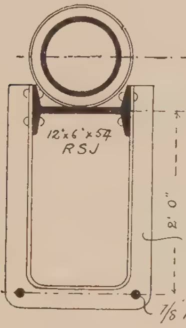


FIG. 342.

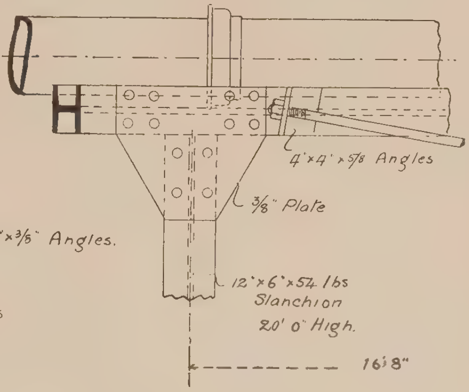


FIG. 343.

$$\frac{W}{A}\pm\frac{M}{Z}$$

so as to see that the compression and tension are within safe limits, area of joists=15·88 sq. in., maximum compression=7·61 tons.

$$\therefore\quad \frac{7{\cdot}61}{15{\cdot}88}\pm\frac{13{\cdot}85}{9{\cdot}4}$$

=0·48+1·47=1·95 tons per sq. in. compression and 1 ton tension, both easily within safe limits. Figs. 342, 343, 344, 345 show full details. Assuming that the supports are to be steel joists as shown, it would naturally be convenient to use 12-in × 6-in. joist for this if suitable. This can be tested by the Rankine-Gordon formula, as follows :—

$$P=\frac{f}{1+\frac{1}{AC}\left(\frac{l}{r}\right)2},$$

f=allowable stress=10,000 lb.
l=20. r=1·80. A=2. C=9000.

Then P=compression per sq. in.=

$$\frac{10000}{\frac{1}{1+2+9000}\left(\frac{2\cdot0}{1\cdot8}\right)^2}=2 \text{ tons.}$$

The sections, therefore, could be safely used. The tension rods may be calculated by a stress diagram by which the tension is found to be 17,300 lb.=7·85 tons. Allowing a tension of 6½ tons per sq. in., $\frac{7\cdot85}{6\cdot5}$ =say 1·25 sq. in. is required. One could use two ⅞-in. rods, which should, however, have "plus" threads, which will necessitate their being thickened out to 1 in. diameter at the ends. The use of the tension rods, involving as they do, however, a certain amount of smithwork, always unsatisfactory in structural engineering, may be obviated by the construction shown in figs. 346, 347, 348, and 349, by constructing saddles of steel sections and plates. In this case flat bars are used, the tension therein being slightly less than if they were placed as in the previous example, viz. about 18,500 lb., which would easily be borne by two 3-in.×⅜-in. bars, each having a sectional area of 1⅛ sq. in.=combined sectional area of 2¼ sq. in., equal to a load of about 4 tons per sq. in.

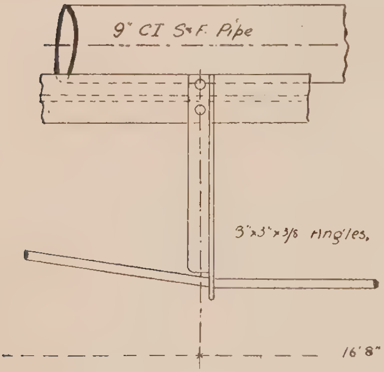


FIG. 344.

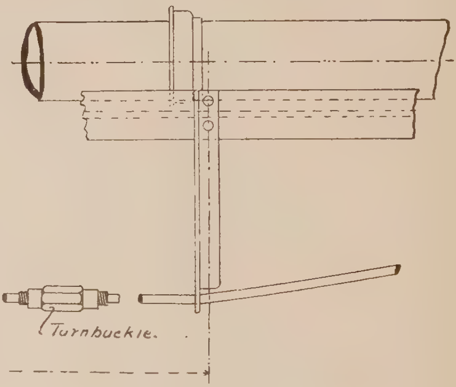
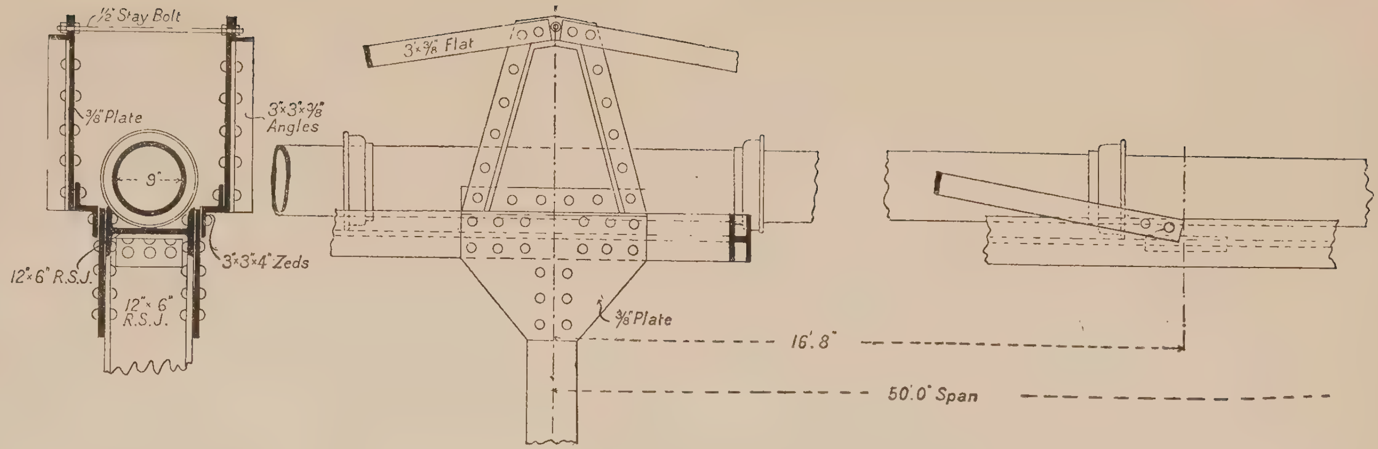


FIG. 345.

In figs. 350 and 351 are shown details of a much simpler piece of work for effecting the carrying of pipes at a high level over ground, etc. The stanchions consist of old flange railway metals embedded in blocks of concrete, to which they are tied by plates. These plates would be fixed to the rail by a piece of angle iron riveted to the flange ; a cross-piece of iron would serve to tie the rails at the top and also support the pipe, which is self-supporting, between the stanchions. It would be tied down to the cross-piece by iron straps. Further details of similar constructions were shown previously in figs. 131–133. Other details will, of course, present themselves to the reader, such as cases where a small bridge of steel, timber, or reinforced concrete would be constructed to carry a line of pipes, fireclay,



Figs. 346, 347, and 348.

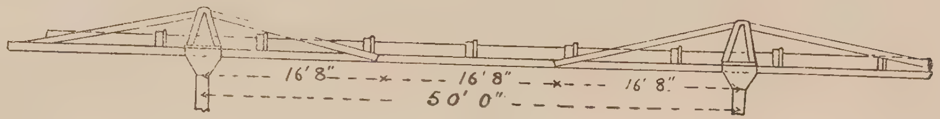


Fig. 349.

or iron, and also serve, perhaps, the purpose of a foot-bridge. Such constructions could not be discussed in a book of this sort dealing with sewage, but are fully considered in *Civil Engineering Practice.* The practice of laying fireclay pipes on a beam or beams of reinforced concrete has been proved successful and economical.

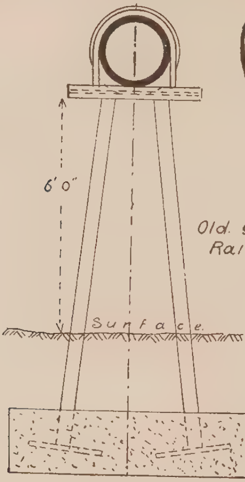


Fig. 350.

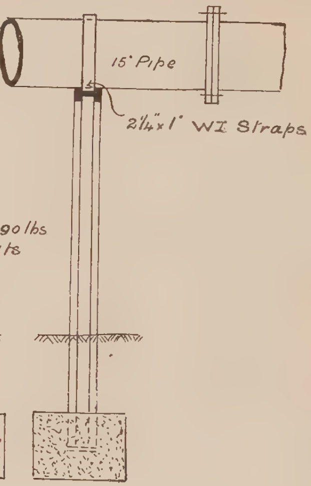


Fig. 351.

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